Areas Contributing Ground Water to the Peconic Estuary, and Ground-Water Budgets for the North and South Forks and Shelter Island, Eastern Suffolk County, New York

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 97-4136

Prepared in cooperation with the
PECONIC ESTUARY PROGRAM and
SUFFOLK COUNTY DEPARTMENT
OF HEALTH SERVICES

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Coram, New York
1998

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Multiply	By	To Obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
	Area	
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon	3.785	liter
	Flow	
gallon per minute (gal/min)	3.785	liter per minute
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
inch per year (in/yr)	25.4	millimeter per year

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Areas Contributing Ground Water to Peconic Estuary, and Ground-Water Budgets for North and South Forks and Shelter Island

By Christopher E. Schubert

Abstract

The Peconic Estuary, at the eastern end of Long Island, has been plagued by a recurrent algal bloom, locally referred to as "Brown Tide," that has caused the severe decline of local marine resources. Although the factors that trigger Brown Tide blooms remain uncertain, ground-water discharge has previously been shown to affect surface-water quality in the western part of the estuary. A U.S. Geological Survey ground-water-flow model of the main body of Long Island indicates that a total of about 7.5 x 10^6 ft^3/d (cubic feet per day) of freshwater discharges to the western part of the estuary, but the model does not include the ground-water flow systems on the North and South Forks and Shelter Island, which contribute significant amounts of freshwater to the central and eastern parts of the estuary. The need for information on freshwater discharge to the entire estuary prompted the U.S. Geological Survey to evaluate ground-water discharge from the North and South Forks and Shelter Island.

Source areas that contribute ground water to the Peconic Estuary were delineated, and ground-water budgets for these areas were developed, to evaluate the distribution and magnitude of ground-water discharge to the central and eastern parts of the estuary. Contributing-area boundaries that were delineated coincide with the hydraulic boundaries of the fresh ground-water-flow systems of the North and South Forks and Shelter Island; these boundaries are of two types—external (saltwater bodies) and internal (ground-water divides). Hydrologic components that were evaluated include recharge from precipitation, public-supply withdrawal and return flow, and agricultural withdrawal. Values for each of these components were calculated or estimated for the individual freshwater flow subsystems that form each ground-water-budget area, then summed to obtain the total discharge of fresh ground water to tidewater.

Ground-water discharge to the Peconic Estuary is about 3.8 x 10^6 ft^3/d from the North Fork, 11 x 10^6 ft^3/d from the South Fork, and 1.7 x 10^6 ft^3/d from Shelter Island. The total contribution to the estuary from these areas is about 16 x 10^6 ft^3/d—roughly twice the total contribution from the main body of Long Island. In contrast to the freshwater contribution from the main body of Long Island, which is concentrated near the head of the estuary, the contributions from the North and South Forks and Shelter Island are distributed along the east-west length of the estuary.

Changes in water-table altitude and the resulting changes in total discharge to the Peconic Estuary were estimated from the relative changes in annual mean water level at observation wells. The 1985-95 interval included 7 years (1985-88, 1991-92, 1995) of generally below-average water-table altitudes that presumably caused similar decreases in ground-water discharge to the estuary; intense Brown Tide blooms coincided with six of these years (1985-88, 1991, 1995), and localized blooms coincided with the remaining year (1992). Water-table altitudes in the remaining 4 years of the 1985-95 interval (1989-90, 1993-94) were nearly average or above average, and presumably produced comparably near-average or increased amounts of ground-water discharge to the estuary; none of these years saw any widespread Brown Tide blooms. Fluctuations in the amounts of ground-water discharge to the estuary appear to affect the occurrence of Brown Tide blooms, although the factors that trigger the blooms have not been determined.

INTRODUCTION

The Peconic Estuary, which consists of an interconnected series of shallow coastal embayments at the eastern end of Long Island, N.Y. (fig. 1), has been repeatedly plagued since 1985 with an unusual algal bloom of a previously unknown species (*Aureococcus anophagefferens*) (Suffolk County Department of Health Services, 1992). Adverse effects of the algal bloom, locally referred to as “Brown Tide,” include the severe decline of major shellfisheries and a sharp reduction in the abundance of eelgrass (*Zostera marina*) beds, which provide critical habitat for commercially important finfish as well as shellfish. Although the onset, duration, and cessation of the Brown Tide bloom remain unpredictable (Peconic Estuary Program [PEP] Program Office, 1996), the Brown Tide Comprehensive Assessment and Management Program (BTCAMP), begun by the Suffolk County Department of Health Services (SCDHS) in 1988, has found that the blooms are not triggered by conventional macronutrients, but possibly by other factors, such as atypical climatic patterns and specific chemicals (chelators, specific organic nutrients, certain metals) (Suffolk County Department of Health Services, 1992). Detailed information on the spatial and temporal occurrence of Brown Tide blooms in the Peconic Estuary through the summer of 1992 are given in the BTCAMP report (Suffolk County Department of Health Services, 1992).

Estuarine surface-water-quality monitoring and numerical modeling conducted under the BTCAMP effort have found that ground-water discharge to the Peconic River and Flanders Bay, at the head of the Peconic Estuary (fig. 2), affects surface-water quality in the western, most eutrophic part of the estuary. In 1992, the Peconic Estuary was included in the National Estuary Program, administered by the U.S. Environmental Protection Agency under Section 320 of the Clean Water Act, and the Peconic Estuary Program (PEP) subsequently began under the coordination of the SCDHS. On the basis of the BTCAMP results, one of the primary efforts of the PEP is to obtain information on ground-water discharge to the entire Peconic Estuary for use in estuarine surface-water modeling and evaluations of management alternatives, and in the development of watershed-management efforts.

A U.S. Geological Survey (USGS) numerical ground-water-flow model of the main body of Long Island (Buxton and others, 1991) has yielded estimates of ground-water discharge to the western part of the

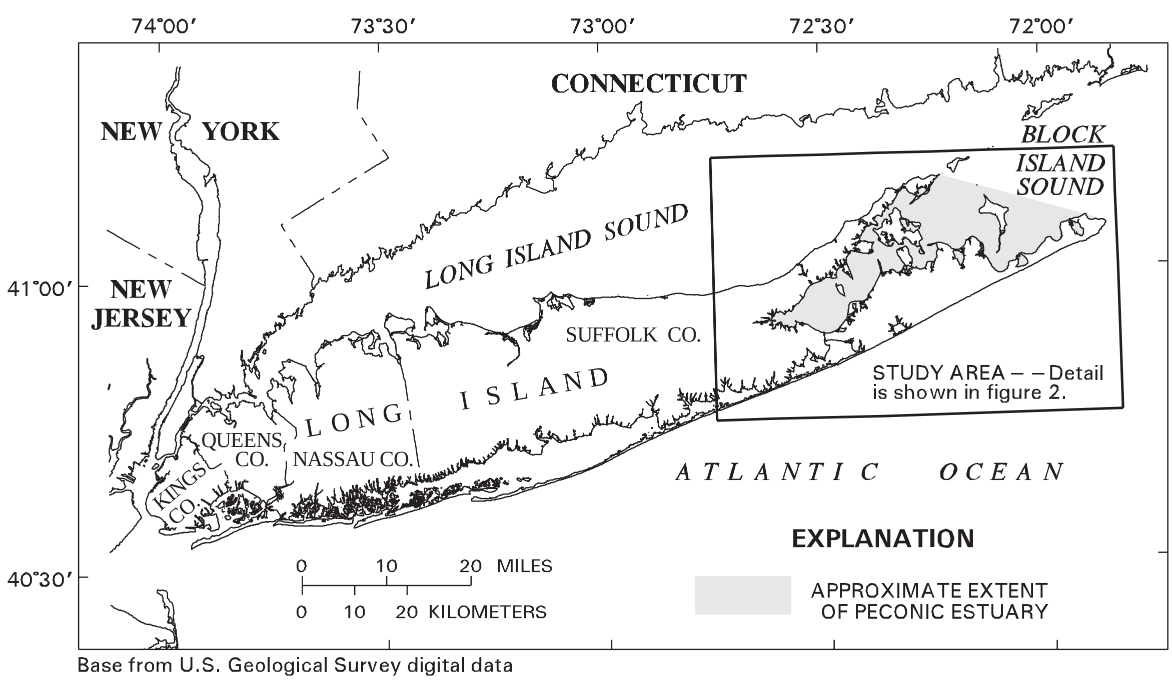
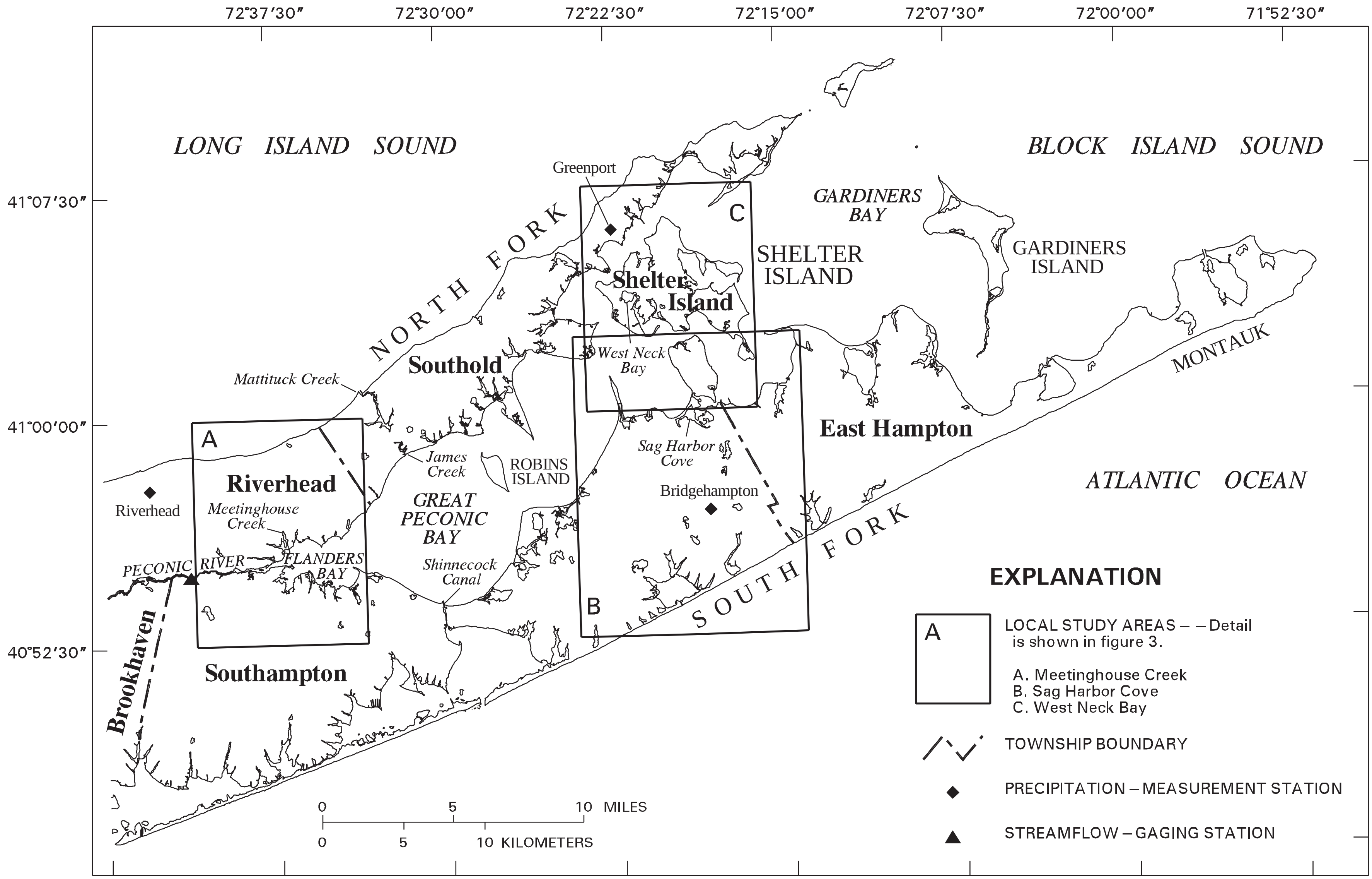


Figure 1. Location of the Peconic Estuary and study area in eastern Suffolk County, Long Island, N.Y.



Base from U.S. Geological Survey digital data

Figure 2. Locations of the North and South Forks and Shelter Island, local study areas (Meetinghouse Creek, Sag Harbor Cove, and West Neck Bay), selected precipitation-measurement stations, and Peconic River streamflow-gaging station in eastern Suffolk County, N.Y.

Peconic Estuary. The model simulates equilibrium conditions during a period (1968-83) in which average precipitation was comparable to the long-term mean, and public-supply withdrawals were relatively stable (H.T. Buxton and D.A. Smolensky, U.S. Geological Survey, written commun., 1996); these conditions are assumed to still apply in eastern Suffolk County at present (1996). Details on the extent of the numerical-model grid and on model representation of aquifers, confining units, and boundary conditions are given in Buxton and others (1991). Results indicate that a total of about 7.5 x 10^6 ft^3/d of freshwater is discharged from the main body of Long Island and that nearly two-thirds of this amount (about 4.7 x 10^6 ft^3/d) is contributed by the freshwater and estuarine reaches of the Peconic River; the rest is contributed as direct ground-water discharge to Flanders Bay and the western part of Great Peconic Bay (about 1.9 x 10^6 and 0.92 x 10^6 ft^3/d, respectively) (fig. 2). The model does not simulate the ground-water-flow systems on the North and South Forks and Shelter Island, however, which are hydraulically isolated from the ground-water-flow system of the main body of Long Island and contribute freshwater to the central and eastern parts of the estuary (figs. 1 and 2).

The need for information on ground-water discharge to the entire Peconic Estuary prompted the USGS, in cooperation with the PEP and SCDHS, to begin a 3-year investigation in 1993 to (1) delineate the source areas (contributing areas) of ground water that ultimately enters the estuary and develop ground-water budgets for the North and South Forks and Shelter Island, and (2) identify the patterns and rates of ground-water discharge to three small embayments within the estuary. These efforts entailed (1) the use of a geographical information system (GIS) to evaluate the distribution and magnitude of ground-water discharge to the estuary from the North and South Forks and Shelter Island, and (2) the development of ground-water-flow models, coupled with particle-tracking procedures, to analyze ground-water flow paths and traveltime to the three embayments.

Purpose and Scope

This report delineates the areas that contribute ground water to the Peconic Estuary and presents ground-water budgets for the North and South Forks and Shelter Island. (A companion report [C.E. Schubert, U.S. Geological Survey, written commun., 1997] identifies the patterns and rates of ground-water discharge to the three small embayments.) This report also (1) describes the population and land use, water use, and hydrology (precipitation and recharge, hydrologic boundaries, and directions of ground-water flow) of the North Fork, South Fork, and Shelter Island study areas, (2) explains the methods used to delineate contributing areas and to estimate ground-water-budget components, and (3) presents an analysis of fluctuations in ground-water discharge.

Previous Investigations

Many previous studies by the USGS and others have examined the geology and hydrology of the North and South Forks and Shelter Island. The first comprehensive report on the geology of the North and South Forks was provided by Fuller (1914). Reconnaissance studies of the water resources of the North Fork are described by Hoffman (1961) and Crandell (1963); a reconnaissance of the water resources of the Montauk area of the South Fork is described by Perlmutter and DeLuca (1963). Subsequent investigations that have examined the geology and hydrology of the North Fork include Baier and Robbins (1982a), Soren and Stelz (1984), Bohn-Buxton and others (1996), McNew-Cartwright (1996), and Misut and McNew-Cartwright (1996). Reports that describe the geology and hydrology of the South Fork include Holzmacher, McLendon, and Murrel (1968), Fetter (1971, 1976), Berkebile and Anderson (1975), Bart and others (1976), Nemickas and others (1977), Baier and Robbins (1982b), Nemickas and Koszalka (1982), Prince (1986), and Cartwright (1997). The hydrogeology of Shelter Island is reported by Soren (1978) and Simmons (1986).

Several previous investigations have characterized ground-water discharge from parts of the Long Island ground-water-flow system. A comprehensive water budget for Nassau County and most of the main body of Suffolk County is given in Franke and McClymonds (1972), and provides estimates of ground-water discharge to the northern and southern shores of Long Island. A description of the ground-water resources of Suffolk County is given in the Comprehensive Water Resources Management Plan (Suffolk County Department of Health Services, Dvirka and Bartilucci, and Malcolm Pirnie, Inc., 1987), and provides a summary of ground-water discharge information for this area. Bohn-Buxton and others (1996) simulate ground-water flow paths and traveltime for two small areas on the North Fork, and provide information on the local patterns and rates of ground-water discharge to the adjacent tidewaters of the Peconic Estuary; more work would be needed, however, to determine whether these results apply to other coastal areas of the estuary.

Acknowledgments

The author thanks Vito Minei and Walter Dawydiak of the PEP Program Office for their technical support and cooperation during the investigation. Thanks are also extended to several individuals who provided information or assisted with data collection during the investigation: Edward Olson, Ronald Paulsen, and Thomas Nanos of the SCDHS; Dewitt Davies of the Suffolk County Planning Department; Steven Colabufo, Jeff Altofer, and Paul Kuzman of the Suffolk County Water Authority; Allan Connell of the Natural Resources Conservation Service; Kathryn Vreeland of the Northeast Regional Climate Center; Frank Iannazzo, Frank Basile, Brian Boogertman, and John Brennan of the SCDHS well-drilling crew; and Conrad Strebel and others of the Delta Well and Pump, Inc. well-drilling crew.

DESCRIPTION OF STUDY AREA

The North Fork investigation focused on the area east of Mattituck Creek and James Creek and encompassed most of the Town of Southold, including adjacent Robins Island (fig. 2). The South Fork investigation focused on the area east of Shinnecock Canal and encompassed the eastern half of the Town of Southampton and the Town of East Hampton, including adjacent Gardiners Island. The Shelter Island investigation encompassed all areas within the Town of Shelter Island. Additional detailed study to help refine the delineation of contributing areas focused on three local areas encompassing the uplands of the three small embayments (Meetinghouse Creek, Sag Harbor Cove, and West Neck Bay) that are the subject of concentrated watershed-management efforts under the PEP (fig. 2). The Meetinghouse Creek study area encompasses 44.8 mi^2 near the west end of the North Fork (fig. 3A); the Sag Harbor Cove study area encompasses 61.4 mi^2 in the central part of the South Fork (fig. 3B); and the West Neck Bay study area encompasses the entire 12.0-mi^2 area of Shelter Island (fig. 3C).

Population and Land Use

The year-round population of the five eastern Suffolk County Townships—East Hampton, Riverhead, Shelter Island, Southampton, and Southold (fig. 2)—on January 1, 1991 is estimated by the Long Island Lighting Company (1991) to have been about 107,000. During the summer, an additional 171,000 seasonal residents and tourists visit the area for its rural and agricultural character, natural beauty, and recreational opportunities (Long Island Regional Planning Board, 1987; Suffolk County Department of Health Services, 1992).

Land-use analyses by the Long Island Regional Planning Board in 1982 indicate that land in the five eastern Suffolk County Townships (East Hampton, Riverhead, Shelter Island, Southampton, and Southold) in 1981 was 42 percent vacant, 20 percent agricultural, 13 percent residential, and 12 percent recreational and open space. Vacant land was predominant in the Towns of East Hampton (52 percent), Southampton (49 percent), and Southold (40 percent); agricultural land was predominant in the Town of Riverhead (40 percent); and recreational land and open space was predominant in the Town of Shelter Island (41 percent) (Long Island Regional Planning Board, 1982). The extent of agricultural land in the five eastern Suffolk County Townships in 1994, based on preliminary GIS analyses by the Suffolk County Planning Department of Township tax-assessor designations (Dewitt Davies, Suffolk County Planning Department, written commun., 1995), is shown in figure 4.

Water Use

Ground water is the sole source of drinking water in Suffolk County, and the communities within the study area are served by seven regional public water-supply systems at present (1996) (fig. 5). The service-area locations indicated for the Greenport, Hampton Bays, and Riverhead Water Districts in figure 5 are based on a GIS coverage assembled by the SCDHS

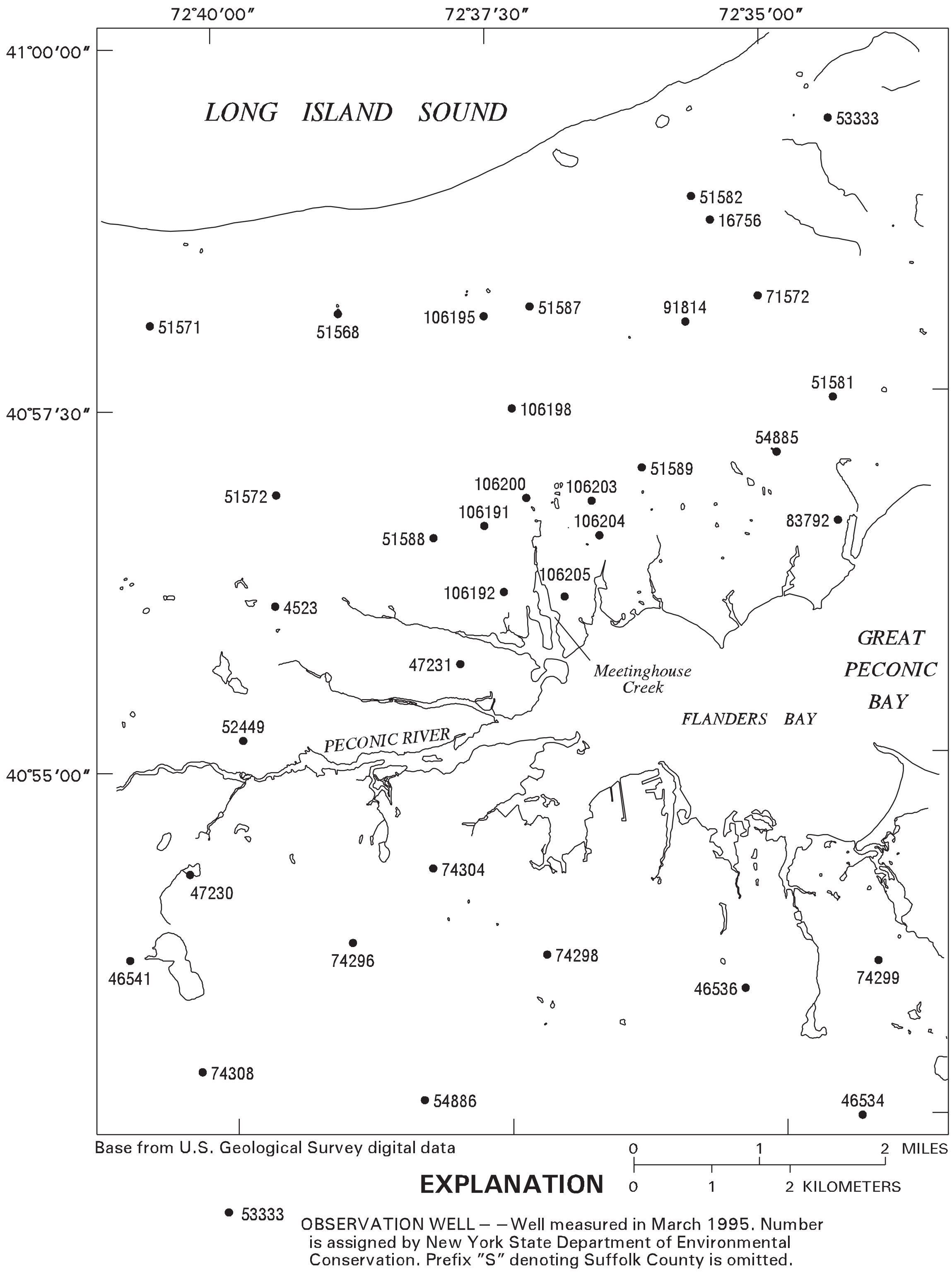


Figure 3A. Locations of observation wells in the Meetinghouse Creek study area, eastern Suffolk County, N.Y. (Location of study area is shown in fig. 2.)

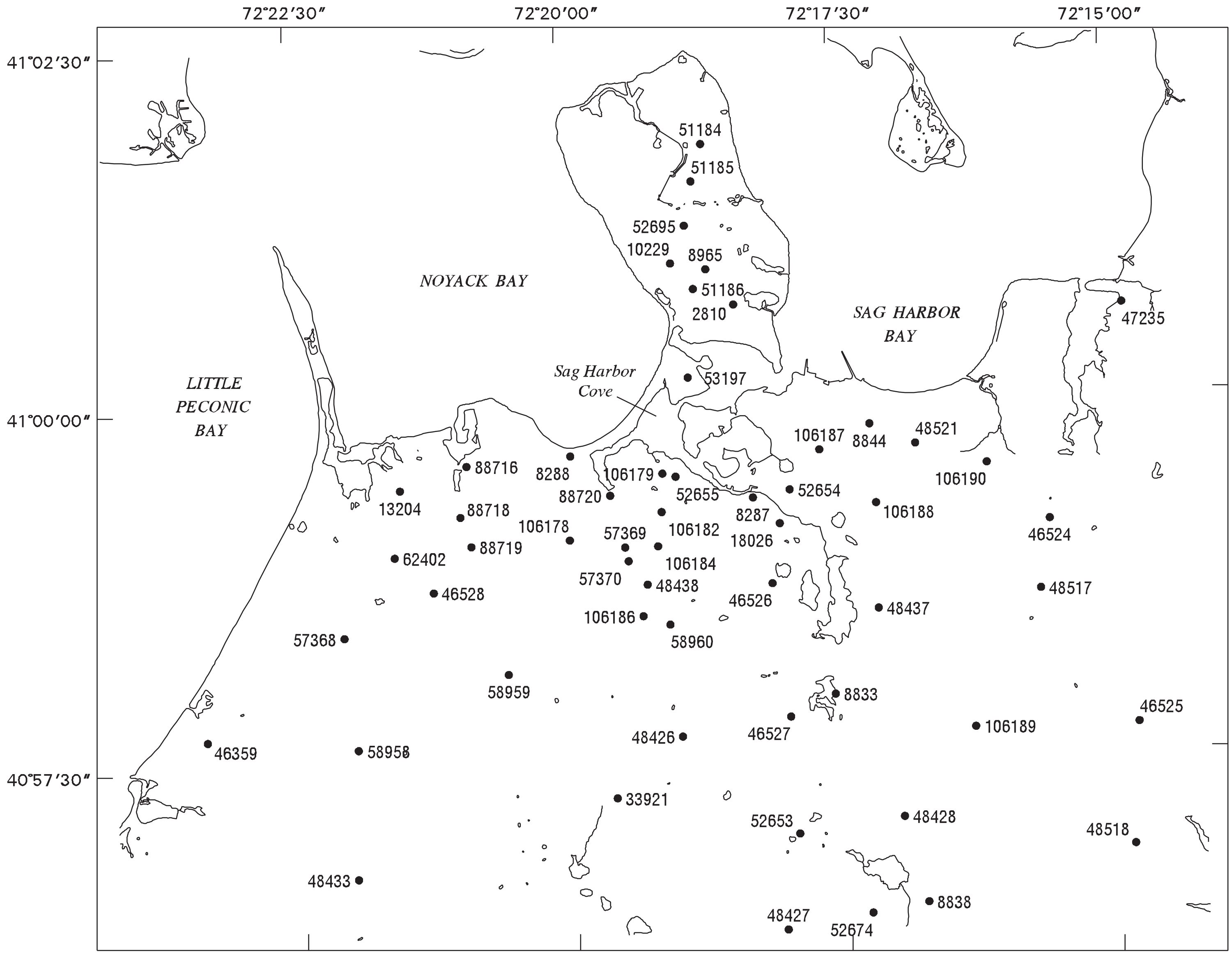
(Dennis Jackson, Suffolk County Department of Health Services, written commun., 1995); the service-area locations for the East Hampton, Montauk, Southampton, and Westhampton distribution zones of the Suffolk County Water Authority (SCWA) were digitized in this study from the SCWA's 1995 distribution-system maps (Jeff Altofer, Suffolk County Water Authority, written commun., 1996).

Well-field locations for the Greenport Water District, which withdraws ground water from and distributes water supply to communities on the North Fork, were digitized from a 1992 map of existing and proposed facilities (Roy F. Weston, Inc., 1992); well-field locations for the East Hampton, Montauk, and Southampton distribution zones of the SCWA, which withdraw ground water from and distribute water supply to communities on the South Fork, were digitized from the SCWA's 1995 distribution-system maps (Jeff Altofer, Suffolk County Water Authority, written commun., 1996). Monthly pumpage in 1994 (table 1) was compiled for each well field associated with the Greenport Water District (T.A. Nanos, Suffolk County Department of Health Services, written commun., 1995, 1996) and the East Hampton, Montauk, and Southampton distribution zones of the SCWA (Paul Kuzman, Suffolk County Water Authority, written commun., 1995). Monthly pumpage in 1994 also was compiled for the Hampton Bays and Riverhead Water Districts (T.A. Nanos, Suffolk County Department of Health Services, written commun., 1995, 1996), which distribute water supply to, but do not withdraw ground water from, selected communities on the extreme western part of the South Fork and within the Meetinghouse Creek study area, respectively (figs. 2 and 5, and table 1). The Westhampton distribution zone of the SCWA was not considered in this investigation because it neither withdraws ground water from, nor distributes water supply to, communities on the North Fork, South Fork, or Shelter Island, nor the areas of detailed study.

Most of the water pumped for public supply is eventually returned to the water table, mainly through cesspools and septic tanks and, to a lesser extent, as leakage from the water-distribution system; the rest is lost through consumptive water use. Calculations of the rate of infiltration of public-supply water to the water table indicate that, in unsewered areas of Long Island, about 85 percent of total public water-supply pumpage is returned to the ground-water system (Franke and McClymonds, 1972; Suffolk County Water Authorty, 1996). In general, communities not served by the regional public water-supply systems derive drinking water from local water-supply systems or private wells and return most of this water to the ground-water system in nearly the same area from which it was withdrawn; therefore, the withdrawal and return flow of local- or private-supply water was not considered in this investigation.

Ground water also is used for crop irrigation in the study area. Information on the amount of irrigation water that is derived from private wells generally is unavailable because the actual pumping rates typically are less than the New York State Department of Environmental Conservation's required reporting level of 45 gal/min. Nevertheless, the consumptive water use and seasonal irrigation requirement of crops can be estimated from crop-evapotranspiration calculations and the average crop-emergence date and length of growing season as determined by the Natural Resources Conservation Service (NRCS) (A.S. Connell, Natural Resources Conservation Service, written commun. 1995). These NRCS data were used with long-term mean growing-season precipitation data to calculate the seasonal irrigation requirements for the major crops grown on the North and South Forks and Shelter Island. The acreage, growing season, evapotranspiration rate, precipitation rate, and irrigation requirement for eight major crops are summarized in table 2.

Calculations of the seasonal irrigation requirement assume that crops are grown under optimum moisture conditions. These conditions could provide somewhat more water than is needed by crops grown to meet market requirements (A.S. Connell, Natural Resources Conservation Service, oral commun., 1995); therefore, the calculations could overestimate the amount of irrigation water actually used. Alternatively, the transmission and delivery of ground water withdrawn for most irrigation purposes can entail significant volume losses, which would result in underestimation of the average amount of water actually withdrawn for irrigation. These opposing assumptions probably counteract one another to some degree. Information on crop-irrigation practices from the Cornell Cooperative Extension shows reasonable agreement with the calculations of seasonal irrigation requirement given in table 2 (William Sanok, Cornell Cooperative Extension, oral commun., 1996); therefore, the calculations in table 2 probably can be considered reliable approximations of the average amount of ground water withdrawn for irrigation.


72°22′30″
72°20′00″
72°17′30″
72°15′00″
41°02′30″
41°00′00″
40°57′30″
NOYACK BAY
SAG HARBOR BAY
LITTLE PECONIC BAY
Sag Harbor Cove
51184
51185
52695
10229
8965
51186
2810
47235
53197
106187
8844
48521
106190
88716
8288
106179
52655
88720
52654
13204
88718
106188
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106178
106182
57369
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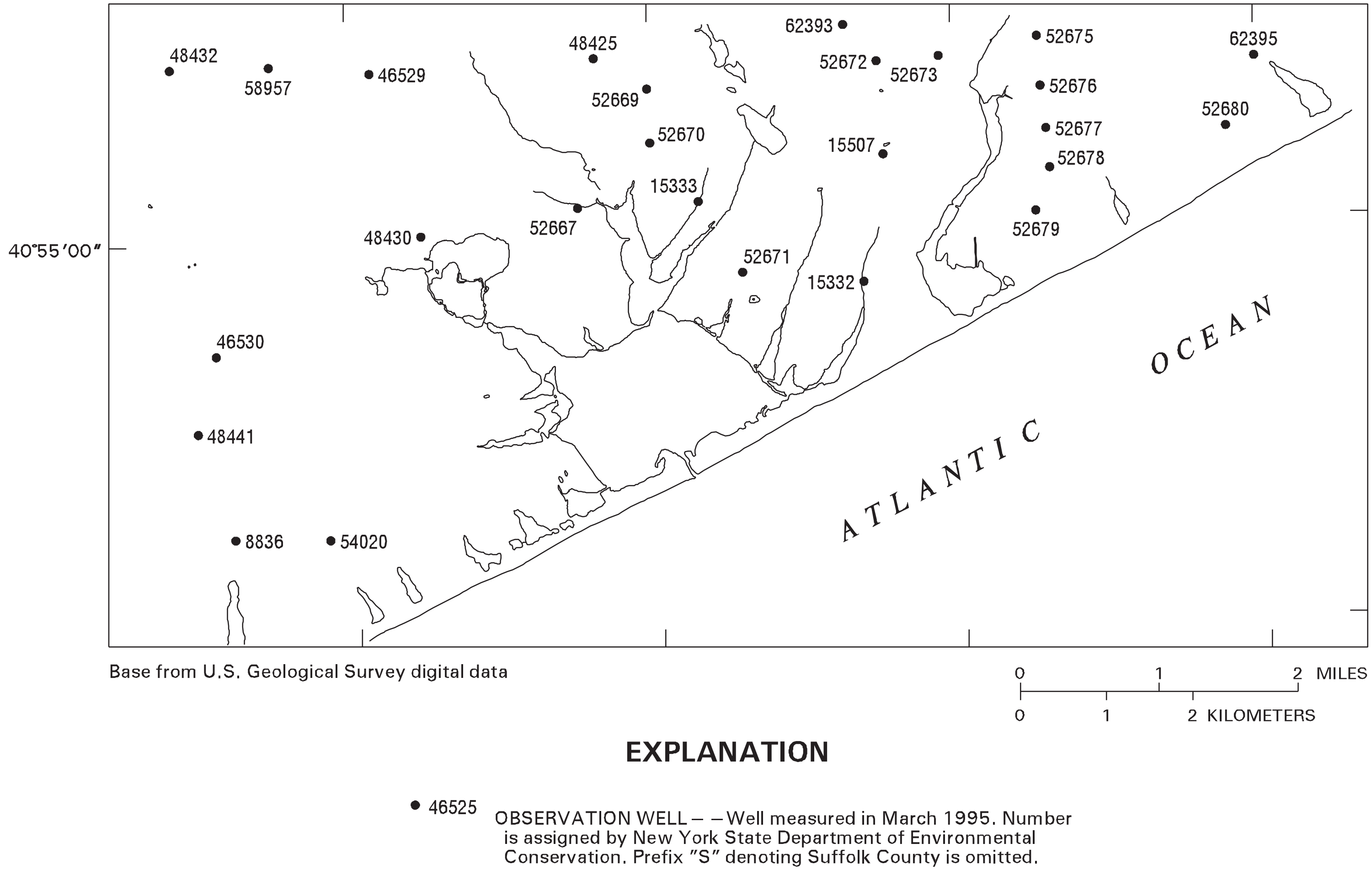


Figure 3B. Locations of observation wells in the Sag Harbor Cove study area, eastern Suffolk County, N.Y. (Location of study area is shown in fig. 2.)

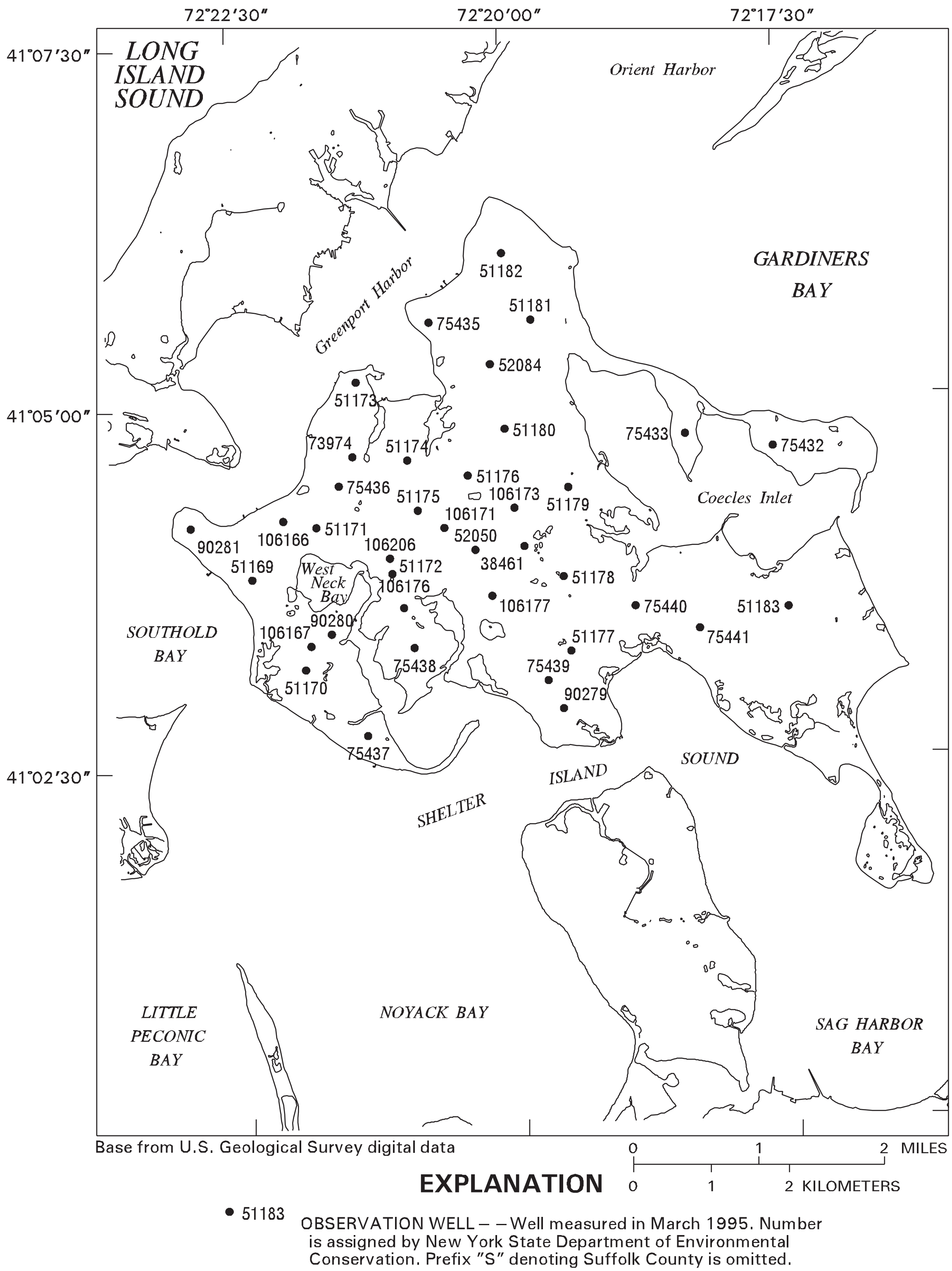


Figure 3C. Locations of observation wells in the West Neck Bay study area, eastern Suffolk County, N.Y. (Location of study area is shown in fig. 2.)

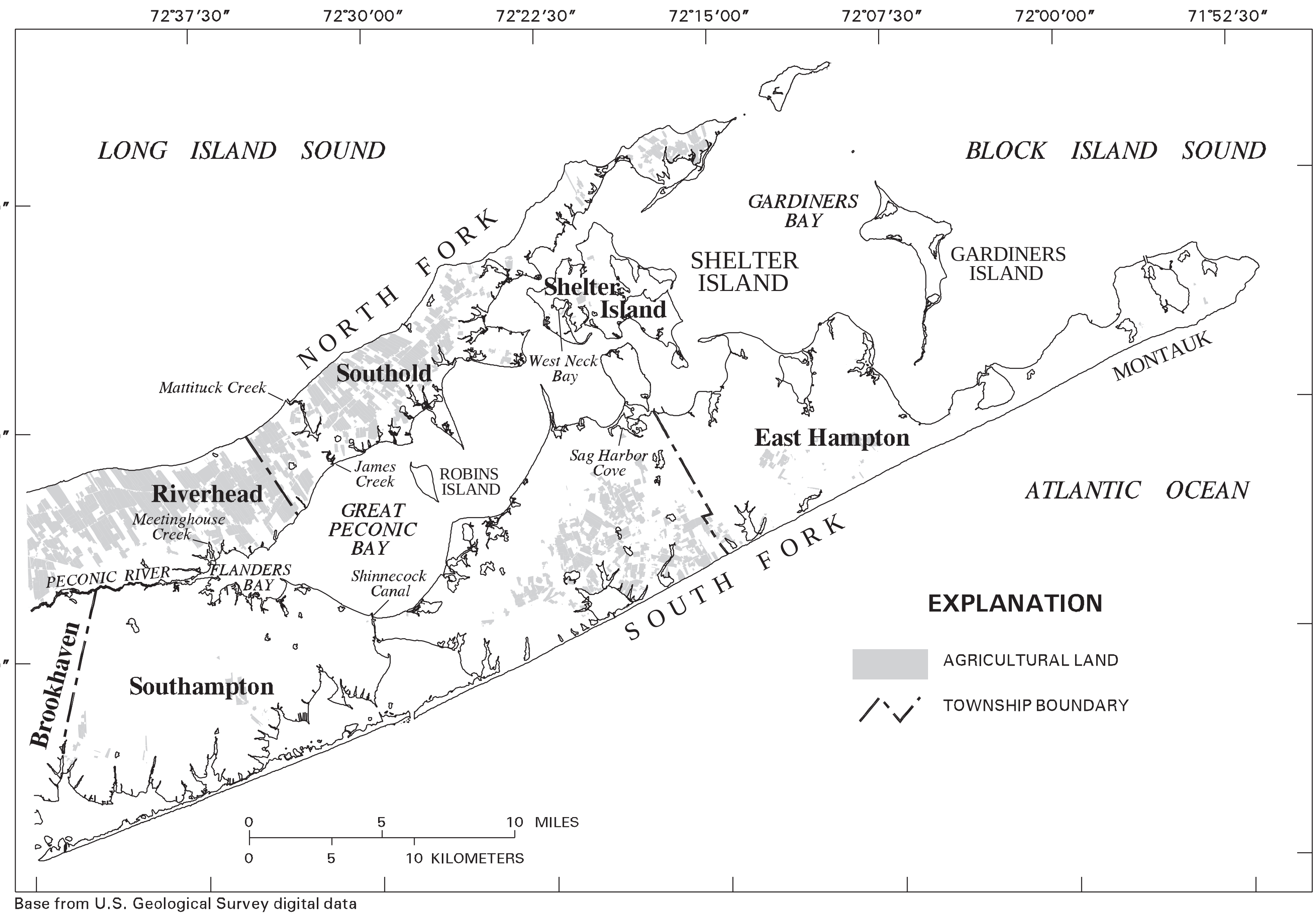


Figure 4. Location of agricultural land in 1994 in East Hampton, Riverhead, Shelter Island, Southampton, and Southold Towns, eastern Suffolk County, N.Y. . (Agricultural land-use data from Dewitt Davies, Suffolk County Planning Department, written commun., 1995.)

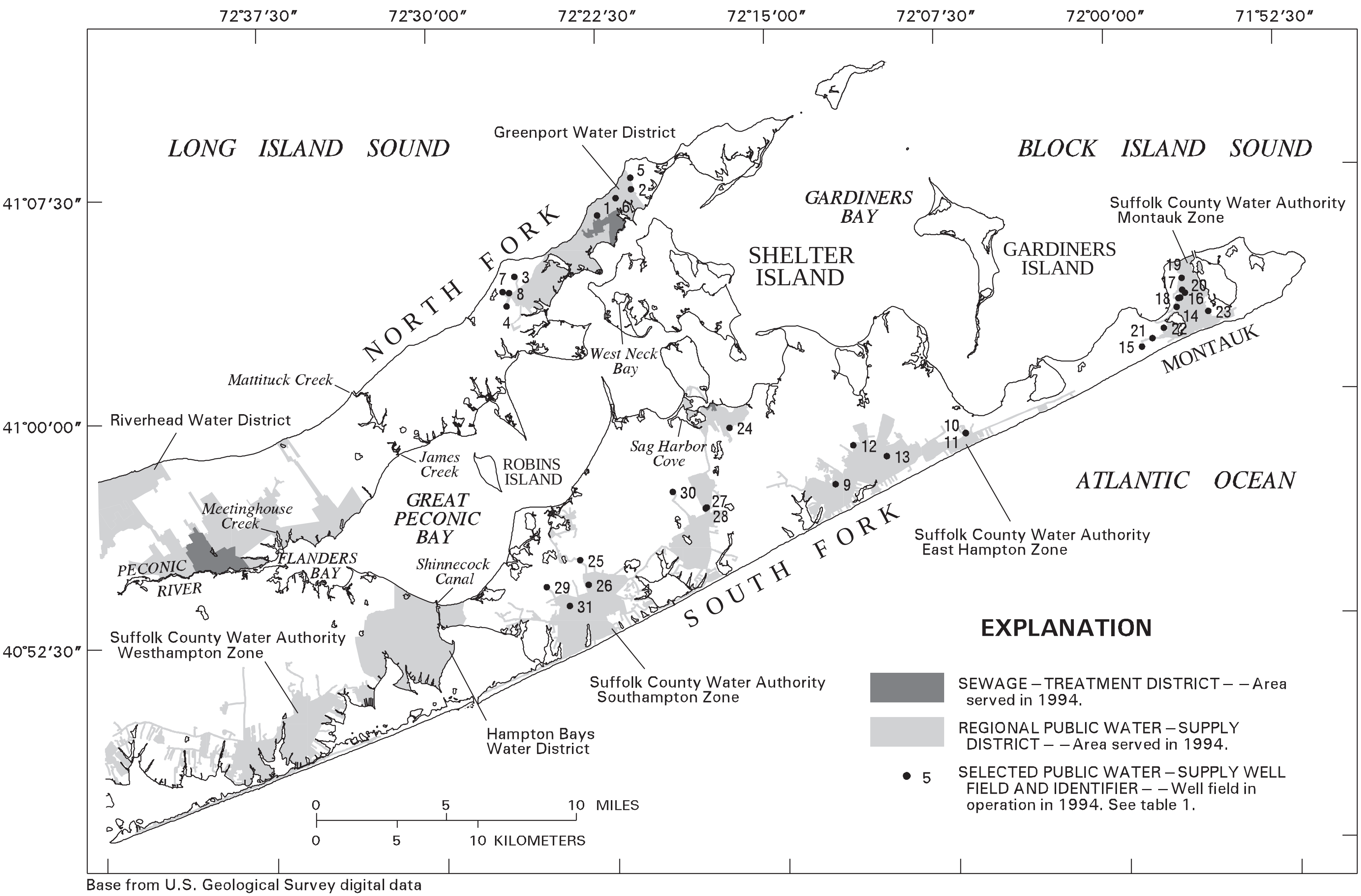


Figure 5. Location of sewage-treatment districts and regional public water-supply districts and selected well fields, eastern Suffolk County, N.Y. (Service-area locations for sewage-treatment districts and Greenport, Hampton Bays, and Riverhead Water Districts from Dennis Jackson, Suffolk County Department of Health services, written commun., 1995. Well-field locations for Greenport Water District from Roy F. Weston, Inc., 1992. Service-area and well-field locations for Suffolk County Water Authority from Jeff Altofer, Suffolk County Water Authority, written commun., 1996.)

Hydrology

The fresh ground-water reservoirs on the North Fork consist of a series of hydraulically distinct freshwater lenses within the upper glacial (water-table) aquifer that generally are bounded laterally and below by saltwater. The fresh ground-water reservoir on Shelter Island consists of an isolated freshwater flow system within the upper glacial (water-table) aquifer that generally is bounded laterally by saltwater and below by a confining unit. All drinking-water and irrigation-water supply on the North Fork and Shelter Island is withdrawn from the upper glacial aquifer because ground water in the deeper aquifers in both areas is mostly saline.

The fresh ground-water reservoir on the main body of the South Fork consists of a principal fresh water flow system that extends through the upper glacial (water-table) and Magothy (deep) aquifers and generally is bounded laterally and below by saltwater. The fresh ground-water systems on the Montauk peninsula and in several localities on the South Fork generally consist of a series of hydraulically distinct freshwater lenses within the upper glacial (water-table) aquifer that are bounded laterally and below by saltwater. Most water supply on the South Fork is withdrawn from the upper glacial aquifer, but some is withdrawn from the underlying Magothy aquifer.

The fresh ground-water system of the Meetinghouse Creek study area extends through the upper glacial (water-table) and Magothy (deep) aquifers and is hydraulically connected to the freshwater flow system of the main body of Long Island. The freshwater flow system is bounded laterally (in areas near the shore) and below by saltwater. Most water supply in this area is supplied from the upper glacial aquifer. Details on the hydrogeology of the North Fork, South Fork, and Shelter Island areas are given in many reports; a description of previous investigations in the study area is presented in the section “Previous Investigations.”

Precipitation and Recharge

The sole source of natural freshwater to the water table in Suffolk County is recharge from precipitation. The amount of recharge is determined by the pattern and rate of precipitation, and by the amount of precipitation that is lost as evapotranspiration and as surface runoff. Although precipitation in Suffolk County is fairly evenly distributed throughout the year (Petersen, 1987), evapotranspiration is greatest during the summer (growing season); therefore, most recharge takes place during the fall, winter, and spring. Seasonal fluctuations in recharge generally are greater than any annual or longer term fluctuations.

Long-term daily records for the precipitation-measurement stations at Bridgehampton, Greenport, and Riverhead (fig. 2) were obtained from the Northeast Regional Climate Center (Kathryn Vreeland, Northeast Regional Climate Center, written commun., 1995) and used to calculate long-term averages (table 3). Long-term mean annual precipitation at Bridgehampton, Greenport, and Riverhead are nearly identical, with values of 45.4, 44.8, and 45.6 in., respectively.

Estimates of the percentage of precipitation that becomes recharge on Long Island were reviewed and summarized by Peterson (1987) and are generally consistent with a recharge rate equal to about 50 percent of mean annual precipitation. An alternative method of calculating recharge (Steenhuis and others, 1985) specifies an annual recharge rate equal to 75 to 90 percent of precipitation from October 15 through May 15. Calculations of recharge based on 50 percent of long-term mean annual precipitation are similar to those based on 75 to 90 percent of long-term mean precipitation from October 15 through May 15 at Bridgehampton, Greenport, and Riverhead (table 3).

Hydrologic Boundaries

The natural hydrologic boundaries of the fresh ground-water reservoirs on the North and South Forks and Shelter Island consist of the hydrologic features that bound the extent of the individual freshwater flow systems, and the hydraulic stresses that control the rate at which freshwater enters and exits the flow systems. The recharge boundary is the water table, where freshwater enters through infiltration of precipitation and as return flow of public-supply water (in unsewered areas). Discharge boundaries are near the shore, where freshwater exits as seepage across the seabed into saline surface waters or as seepage through confining layers into sediments bearing saline ground water. Discharge boundaries also are where the land surface intersects the water table and freshwater exits as seepage to streams or as wetland evapotranspiration. The freshwater/saltwater interface, where freshwater is separated from denser saltwater by a zone of diffusion, acts as a relatively impermeable boundary that moves

Table 1. Monthly pumpage in 1994 for selected regional public water-supply districts, eastern Suffolk County, N.Y.

[Location of public water-supply districts and well fields shown in fig. 5. Pumpage data for Greenport, Hampton Bays, and Riverhead Water Districts from T.A. Nanos, Suffolk County Department of Health Services, written commun., 1995, 1996. Pumpage data for Suffolk County Water Authority from Paul Kuzman, Suffolk County Water Authority, written commun., 1995]

Well field		Pumpage (thousands of gallons)												
Map number	Name	January	February	March	April	May	June	July	August	September	October	November	December	Total
GREENPORT WATER DISTRICT														
1	Plant number 3	30	0	33	0	0	3	0	54	0	39	0	8	167
2	Plant number 4	60	0	90	0	58	54	0	449	42	0	35	48	836
3	Plant number 6	7,580	5,839	4,468	4,354	4,023	11,604	9,420	1,509	1,509	6,178	2,995	2,100	61,579
4	Plant number 7	9,321	9,440	11,677	8,332	7,891	12,538	9,718	15,895	11,197	7,893	8,734	7,693	120,329
5	Plant number 8	0	0	21	0	0	36	5	14	13	0	12	18	119
6	Plant number 9	0	0	22	0	0	541	1,214	2,002	2,508	2,661	2,132	2,624	13,704
7	Plant number 12	2,567	1,218	3,449	5,165	7,969	8,737	15,244	10,984	9,694	5,541	5,000	3,960	79,528
8	Plant number 15	4,698	3,821	3,758	6,172	9,489	9,483	15,304	9,768	6,191	3,745	2,246	3,973	78,648
	Total	24,256	20,318	23,518	24,023	29,430	42,996	50,905	40,675	31,154	26,057	21,154	20,424	354,910
HAMPTON BAYS WATER DISTRICT														
	Total	38,396	34,183	35,006	39,225	63,254	106,846	132,082	98,250	76,535	56,349	39,709	33,137	752,972
RIVERHEAD WATER DISTRICT														
	Total	77,170	64,985	71,024	86,082	122,022	222,249	256,382	156,971	137,700	109,263	75,896	73,734	1,453,478
SUFFOLK COUNTY WATER AUTHORITY—EAST HAMPTON ZONE														
9	Bridgehampton Road	3,605	5,060	4,770	9,580	23,610	40,300	48,400	45,330	34,340	22,640	18,390	5,960	261,985
10	Cross Highway #1	754	807	795	863	848	6,267	9,244	5,387	5,184	1,892	411	425	32,877
11	Cross Highway #2	591	453	591	529	747	3,228	5,160	4,230	3,170	1,521	315	322	20,857
12	Oakview Highway	16,846	14,911	6,310	6,787	19,260	28,798	43,960	36,925	26,176	25,711	4,148	5,225	235,057
13	Spring Close Highway	8,588	5,727	15,311	16,638	20,540	40,146	40,154	27,489	17,940	11,411	10,565	14,632	229,141
	Total	30,384	26,958	27,777	34,397	65,005	118,739	146,918	119,361	86,810	63,175	33,829	26,564	779,917

Table 1. Monthly pumpage in 1994 for selected regional public water-supply districts, eastern Suffolk County, N.Y.—continued

Well field		Pumpage (thousands of gallons)												
Map number	Name	January	February	March	April	May	June	July	August	September	October	November	December	Total
	SUFFOLK COUNTY WATER AUTHORITY—MONTAUK ZONE													
14	Edgemere Road	55	0	0	0	0	312	6,334	7,542	4,205	986	371	415	20,220
15	Edison Drive	1,974	2,116	1,009	294	396	1,703	3,454	2,678	2,825	2,389	1,213	1,541	21,592
16	Fairmont Avenue	1,952	1,069	1,610	1,620	3,536	4,039	3,852	2,585	589	471	1,900	1,331	24,554
17	Farrington Road	3,227	1,285	2,596	3,565	6,065	8,347	9,007	9,193	6,180	6,512	3,262	1,484	60,723
18	Flamingo Avenue	2,334	1,751	2,020	2,478	4,456	4,170	4,685	2,180	1,846	1,441	1,911	773	30,045
19	Flamingo Avenue North	293	301	427	329	677	1,608	1,992	2,308	1,534	436	254	248	10,407
20	Flanders Road	698	1,033	113	1,071	1,270	2,777	3,931	3,406	2,101	677	1,346	1,255	19,678
21	Montauk State Boulevard	582	467	603	545	943	7,957	11,409	11,576	8,334	3,529	522	627	47,094
22	South Davis Avenue	2,123	1,400	1,936	1,802	2,685	5,213	7,821	6,191	4,994	5,232	791	738	40,926
23	South Fulton Street	0	0	105	285	225	165	510	270	180	180	150	180	2,250
	Total	13,238	9,422	10,419	11,989	20,253	36,291	52,995	47,929	32,788	21,853	11,720	8,592	277,489
	SUFFOLK COUNTY WATER AUTHORITY—SOUTHAMPTON ZONE													
24	Division Street	19,903	16,332	15,623	20,281	24,325	33,818	38,456	32,027	23,779	26,274	20,134	19,695	290,647
25	Edge of Woods Road	24,209	16,864	21,505	22,114	18,718	42,653	45,720	26,438	20,349	22,300	3,556	21,070	285,496
26	Long Springs Road	2,823	4,048	4,603	3,139	34,999	45,462	72,443	52,577	42,449	23,653	33,100	3,566	322,862
27	Lumber Lane #4	857	1,208	4,895	1,481	2,662	12,788	19,210	17,930	19,101	3,587	759	1,116	85,594
28	Lumber Lane #5	54	162	108	108	108	108	162	54	0	0	0	123	987
29	North Magee Street	4,568	6,096	2,060	10,988	20,729	39,613	50,396	38,759	15,833	10,553	1,225	1,445	202,265
30	Scuttlehole Road	533	344	407	912	5,031	6,353	17,334	9,303	5,411	1,116	693	726	48,163
31	West Prospect Street	168	304	194	132	400	13,827	21,239	26,385	23,769	11,908	105	1,206	99,637
	Total	53,115	45,358	49,395	59,155	106,972	194,622	264,960	203,473	150,691	99,391	59,572	48,947	1,335,651

Table 2. Cultivation characteristics of selected major crops grown on Long Island, N.Y.

[Long-term mean growing season precipitation reported for Riverhead; station location shown in fig. 2. 1991 estimated extent of cultivation from William Sanok, Cornell Cooperative Extension, written commun., 1996. Crop-evapotranspiration and growing-season data from A.S. Connell, Natural Resources Conservation Service, written commun., 1995. Precipitation data from Kathryn Vreeland, Northeast Regional Climate Center, written commun., 1995]

Crop	1991 estimated extent of cultivation		Average growing season	Calculated seasonal evapo-transpiration (ET), in inches	Long-term mean growing season precipitation[a] (P), in inches	Estimated seasonal irrigation requirement[b] (ET minus P), in inches
	Acreage	Percentage of total[c]				
Potatoes	7,500	21.4	4/30 to 7/29	12.9	10.1	2.8
Nursery	5,800	16.5	4/15 to 9/27	24.6	19.6	5.0
Bluegrass sod	4,000	11.4	4/1 to 10/28	32.6	25.0	7.6
Cabbage	1,700	4.8	4/15 to 7/29	13.7	12.1	1.6
Grapes	1,600	4.6	5/1 to 11/7	19.6	22.4	0.0
Sweet corn	1,600	4.6	7/1 to 9/29	10.1	10.8	0.0
Fruit orchard	800	2.2	4/15 to 10/12	26.3	21.4	4.9
Cauliflower	750	2.1	6/15 to 11/12	14.3	17.6	0.0

[a] Growing-season precipitation (P) data incomplete for 1 or more years; data for these years not used to compute long-term mean value.
[b] Negative values (where P exceeds ET) are reported as zero.
[c] Includes 5,000 acres (14.1 percent) of grain (not irrigated) and 6,350 acres (18.3 percent) of other crops.

Table 3. Long-term mean precipitation amounts at Bridgehampton, Greenport, and Riverhead, eastern Suffolk County, N.Y.

[Station locations are shown in fig. 2. Data from Kathryn Vreeland, Northeast Regional Climate Center, written commun., 1995]

Station	Period	Precipitation (inches)			
		Calendar year		October 15 to May 15	
		Total	50 percent of total	75 percent	90 percent
Bridgehampton	1931-94	[a]45.4	[a]22.7	[a]21.4	[a]25.7
Greenport	1959-94	[a]44.8	[a]22.4	[a]19.7	[a]23.7
Riverhead	1949-94	[a]45.6	[a]22.8	20.7	24.9

[a] Precipitation data incomplete for one or more years; data for these years not used to compute long-term mean value.

gradually in response to changes in the balance between recharge and discharge.

Directions of Ground-Water Flow

The movement of fresh ground water on the North and South Forks and Shelter Island is controlled by the distribution of hydraulic properties within the freshwater flow systems, and the hydraulic gradient determines the direction of ground-water flow (from areas of higher hydraulic head to areas of lower hydraulic head). Water levels measured at 246 wells by the USGS and the SCDHS during March-April 1994 were hand contoured and then digitized to produce a water-table map of the study area (pl. 1). Water-table contours on the North Fork and Shelter Island generally parallel the trace of the shore and indicate that ground water flows radially outward from inland water-table mounds.

Water levels measured at selected wells in the north-central part of the South Fork are significantly higher than those on the rest of the South Fork and indicate areas of poorly permeable deposits that are hydraulically isolated from the principal flow system; these water levels were not used to contour the water-table map shown on plate 1. Instead, the contours on plate 1 depict the inferred potentiometric-surface altitude of the upper glacial aquifer below these poorly permeable deposits and represent the approximate distribution of hydraulic head within the principal flow system.

Water levels measured at 195 wells in the three local study areas (Meetinghouse Creek, Sag Harbor Cove, and West Neck Bay) by the USGS and the SCDHS during March 1995 were used to construct detailed water-table maps of these areas. The water-table map of the Meetinghouse Creek study area (fig. 6A) depicts part of the Long Island mainland flow system near the west end of the North Fork and indicates a narrow zone of eastward flow inland that curves northward toward Long Island Sound or roughly southward toward embayments of the Peconic Estuary, including Meetinghouse Creek. The water-table map of the Sag Harbor Cove study area (fig. 6B) depicts part of the principal flow system of the South Fork; the inferred potentiometric-surface configuration shown depicts the approximate distribution of hydraulic head in the upper glacial aquifer below areas of poorly permeable deposits. Ground-water flow is radially outward from the inland water-table mound and generally curves northward toward embayments of the Peconic Estuary, including Sag Harbor Cove, or southward toward the Atlantic Ocean. The water-table map of the West Neck Bay study area (fig. 6C) depicts the freshwater flow system on Shelter Island and indicates that ground water flows radially outward from inland regions of the irregularly shaped water-table mound toward embayments of the Peconic Estuary, including West Neck Bay.

Ground-water levels on the North and South Forks and Shelter Island fluctuate in response to seasonal or annual variations in recharge from precipitation and, to a lesser extent, to changes in water use. Long-term (1950-76) water-level records from wells on the South Fork indicate that the water-table altitude generally declines from May through early October, when recharge is lowest and water use is highest, and generally rises from the end of October through the end of April, when recharge is highest and water use is lowest (Nemickas and Koszalka, 1982). Long-term water-level records from wells on the North Fork (McNew-Cartwright, 1996) and Shelter Island (Simmons, 1986) exhibit similar patterns. Seasonal water-table fluctuations on the South Fork reach a maximum of less than 4 ft in the center of water-table mounds, and a minimum of about 1 ft close to the shore and in proximity to a nearly constant sea level; annual and longer-term water-table fluctuations appear to show a similar pattern, but with a roughly 1-year lag in their response to annual variations in recharge (Nemickas and Koszalka, 1982). Seasonal water-table-altitude fluctuations on the North Fork (McNew-Cartwright, 1996) and Shelter Island (Simmons, 1986) also decrease with proximity to the shore but are generally smaller than those on the South Fork. Seasonal water-table fluctuations within a given year generally exceed the annual and longer-term fluctuations.

AREAS CONTRIBUTING GROUND WATER TO THE PECONIC ESTUARY, AND GROUND-WATER BUDGETS FOR THE NORTH AND SOUTH FORKS AND SHELTER ISLAND

The contributing areas delineated in this study are based on the hydrologic boundaries of the ground-water-flow systems of the North and South Forks and Shelter Island, as inferred from regional and local water-table maps (pl. 1 and fig. 6). The ground-water budgets for these contributing areas consist of calculations or estimates of the principal ground-water-inflow and outflow components of the respective flow systems.

Delineation of Contributing Areas

The contributing-area boundaries defined in this study coincide with the hydraulic boundaries of the fresh ground-water-flow systems of the North and South Forks and Shelter Island. These contributing-area boundaries are of two types—external (saltwater bodies) and internal (ground-water divides). External boundaries are represented by saline ground-water and surface-water bodies that separate or isolate individual freshwater flow systems, and internal boundaries are represented by local and regional ground-water divides that separate flow subsystems, or groups of flow subsystems, from one another within the larger flow systems.

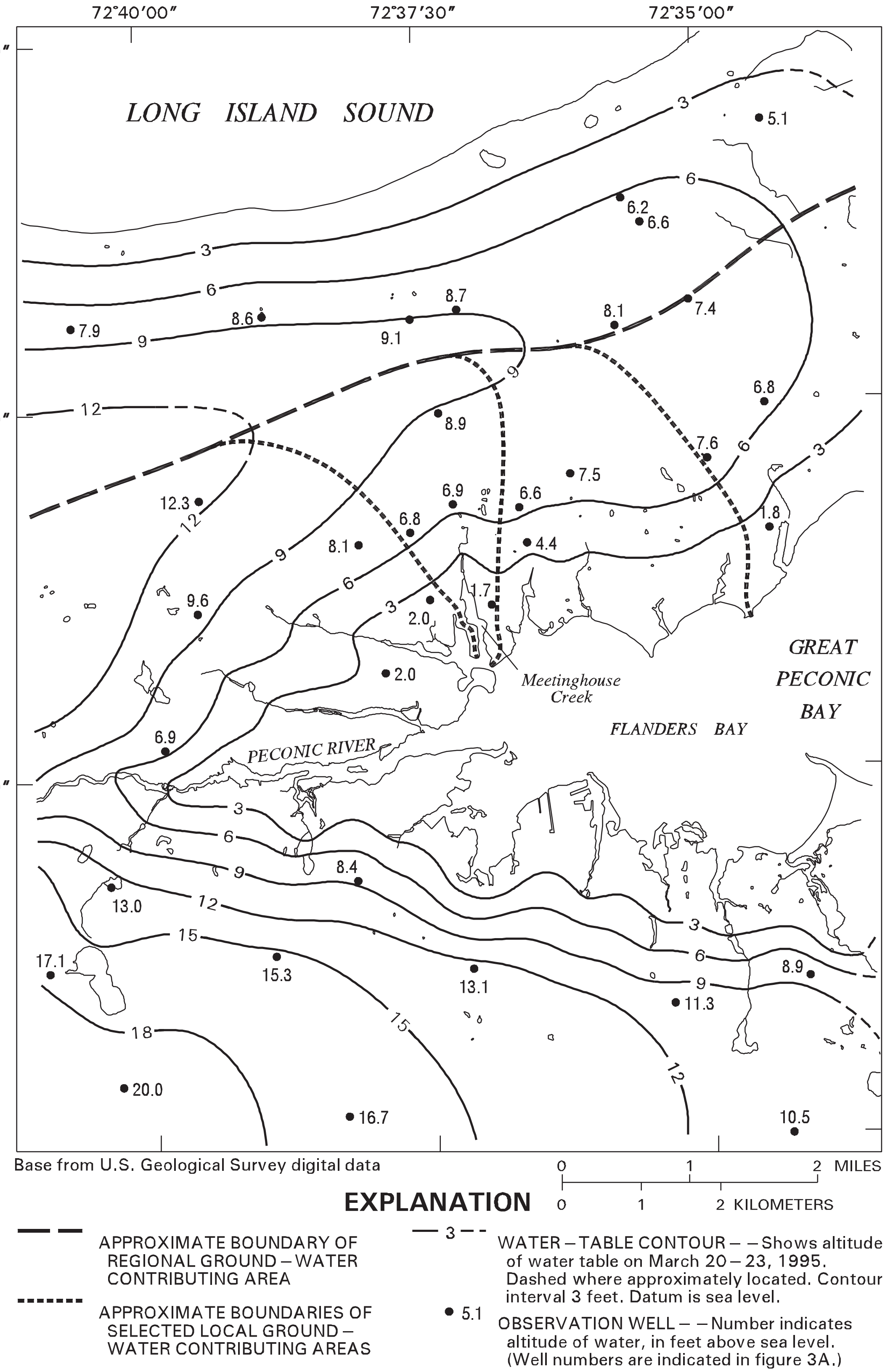


Figure 6A. Water-table altitude in March 1995, water levels in observation wells, and approximate boundaries of areas contributing ground water to selected embayments in the Meetinghouse Creek study area, eastern Suffolk County, N.Y. (Location of study area is shown in fig. 2.)

The water-table configuration on the North and South Forks and Shelter Island (pl. 1) is characterized by a series of isolated water-table mounds, each of which corresponds to a hydraulically distinct freshwater flow system. The North Fork has three oblong water-table mounds east of Mattituck Creek and James Creek (pl. 1) that represent the principal freshwater flow systems; local freshwater flow systems are inferred to coincide with several isolated peninsulas along the southern shore of the North Fork and adjacent Robins Island, but data on these local flow systems are generally lacking. The South Fork has two principal water-table mounds (pl. 1) that correspond to the individual freshwater flow systems of the main body of the South Fork and of the Montauk peninsula; local freshwater flow systems are inferred to coincide with several isolated peninsulas along the northern shore of the South Fork and Gardiners Island, but data on these local flow systems are generally lacking as well. The freshwater flow system on Shelter Island is characterized by one principal water-table mound that contains two local areas of relatively high water-table altitude (pl. 1).

The freshwater flow systems on the North and South Forks and Shelter Island contain a series of flow subsystems, each of which corresponds to the area contributing ground water to an individual coastal embayment. These flow subsystems are generally separated from one another by local and regional ground-water divides that extend inland from the coast and converge toward the respective water-table mounds. Local ground-water divides separating flow subsystems that correspond to the areas contributing ground water to selected embayments within the Peconic Estuary are delineated on plate 1. Regional ground-water divides separating the groups of flow subsystems that correspond to the areas contributing ground water to Long Island Sound, the Peconic Estuary, and the Atlantic Ocean are included on plate 1, and form an inland boundary for contributing areas along the coast of the areas studied.

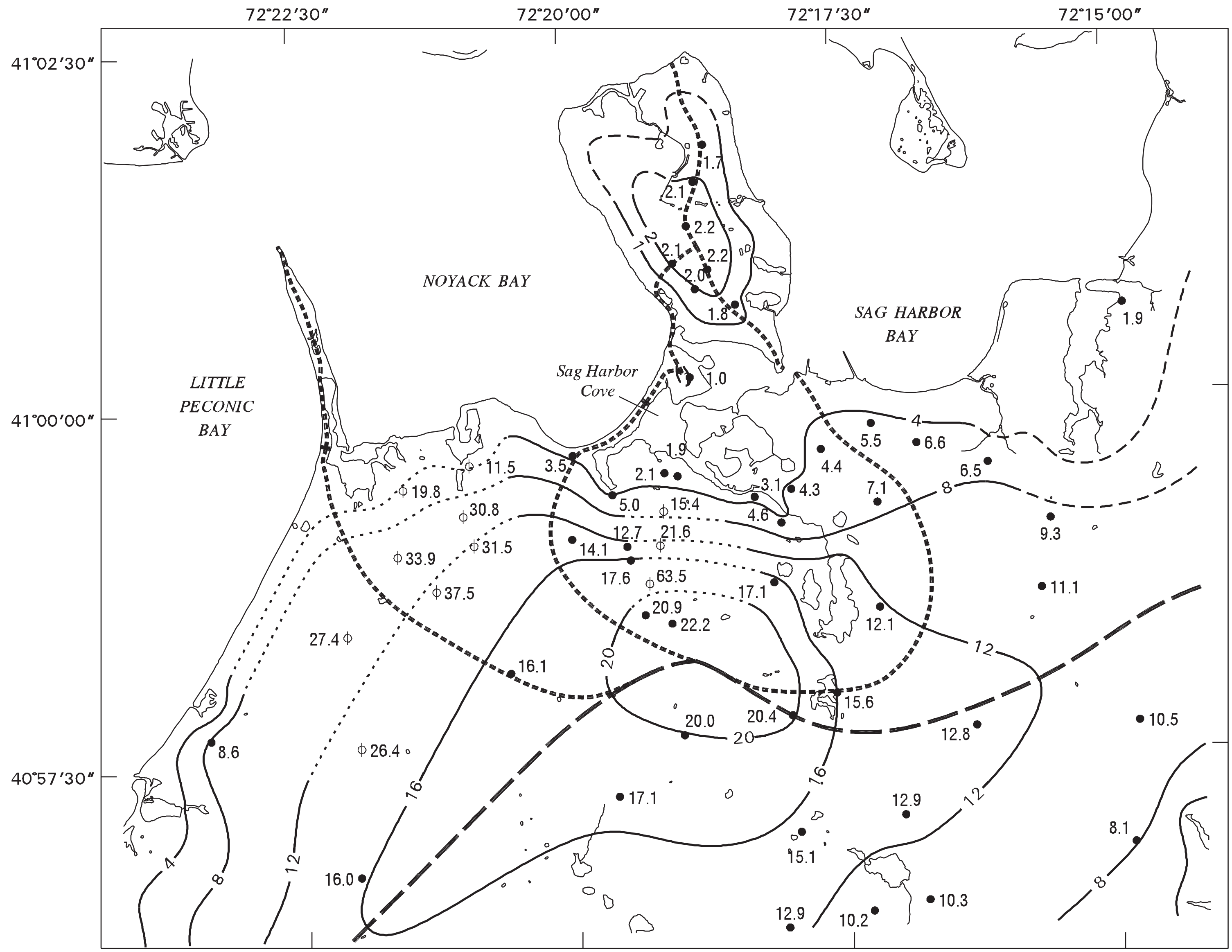
Additional observation wells were installed in each of the three local study areas (fig. 3) to help refine the location of local and regional ground-water divides. Figure 6 (A, B, and C) depicts the water-table configuration and the approximate boundaries of areas contributing ground water to selected embayments within the three local study areas, including Meetinghouse Creek (fig. 6A) on the North Fork, Sag Harbor Cove (fig. 6B) on the South Fork, and West Neck Bay (fig. 6C) on Shelter Island. A composite assemblage of the contributing-area boundaries for selected embayments within the Peconic Estuary (pl. 1 and fig. 6) is shown in figure 7.

Local and regional ground-water divides that separate individual flow subsystems are seldom stationary; rather, they shift in response to seasonal or annual variations in recharge from precipitation or to changes in water use. The amount of recharge is affected by seasonal and longer term fluctuations in the pattern and rate of precipitation, although the effects are generally distributed uniformly across large areas and, therefore, probably do not significantly alter the positions of ground-water divides. In addition, the proximity of the study area to a nearly constant sea level limits the magnitude of water-table-altitude fluctuations and the extent to which water-table mounds can shift and, therefore, probably also limits the movement of ground-water divides. Similarly, the area’s rural character with relatively small public water-supply pumpage (table 1) probably affect most water-table mounds only minimally, although the increased summer pumping could cause local shifts. Thus, the local and regional ground-water divides represented by the contributing-area boundaries in figure 7 should not be interpreted as discrete lines, but rather as narrow zones ranging from a few hundred feet wide near the coast to a few thousand feet wide inland.

Development of Ground-Water Budgets

Hydrologic components that were evaluated for the contributing areas identified in figure 7 were recharge from precipitation, public-supply withdrawal and return flow, and agricultural withdrawal. Values for each of these components were calculated or estimated for the individual freshwater flow subsystems that form each ground-water-budget area and were then summed to obtain the total discharge of fresh ground water from these systems to tidewater.

Recharge from precipitation in land areas and through fresh surface-water bodies was evaluated for all contributing areas identified in figure 7. Recharge to the water table in land areas, calculated as the average of 50 percent of long-term mean annual precipitation at Bridgehampton, Greenport, and Riverhead (table 3), was 22.6 in/yr. Recharge to the water table through fresh surface-water bodies was calculated as the difference between long-term mean annual


72°22'30"
72°20'00"
72°17'30"
72°15'00"
41°02'30"
41°00'00"
40°57'30"
NOYACK BAY
SAG HARBOR BAY
LITTLE PECONIC BAY
Sag Harbor Cove
1.7
2.1
2.2
2.1
2.2
2.0
1.8
1.0
1.9
1.9
2.1
3.5
11.5
19.8
30.8
33.9
31.5
37.5
27.4
26.4
8.6
16.0
16.1
5.0
15.4
12.7
21.6
14.1
17.6
63.5
17.1
20.9
22.2
3.1
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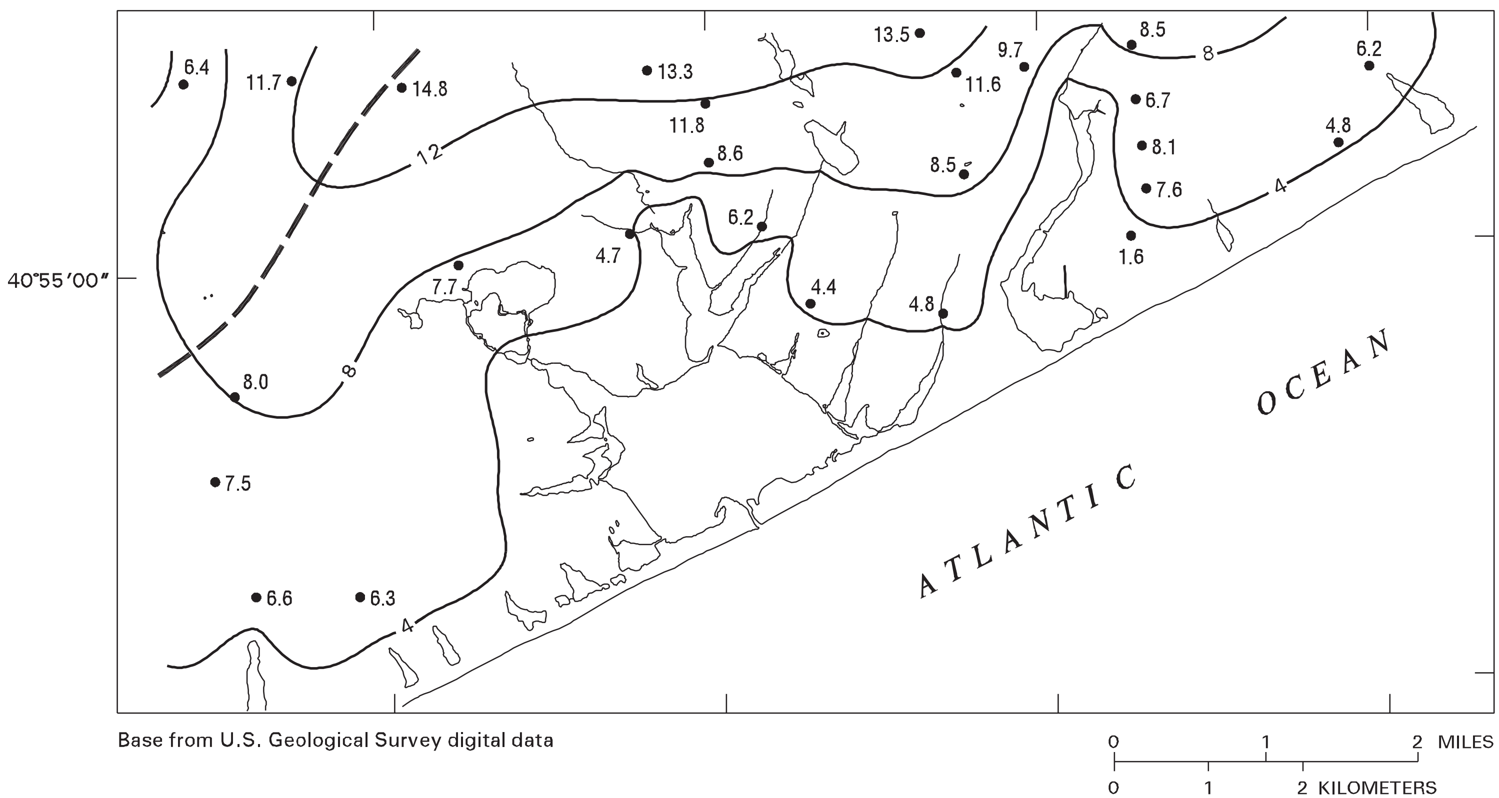

Base from U.S. Geological Survey digital data

EXPLANATION

APPROXIMATE BOUNDARY OF REGIONAL GROUND–WATER CONTRIBUTING AREA

APPROXIMATE BOUNDARIES OF SELECTED LOCAL GROUND–WATER CONTRIBUTING AREAS

— 4 — – WATER–TABLE CONTOUR— —Shows altitude of water table on March 21–23, 1995. Dashed where approximately located. Contour interval, in feet, is variable. Datum is sea level.

POTENTIOMETRIC–SURFACE CONTOUR— —Shows inferred altitude of potentiometric surface of upper glacial aquifer below area of low–permeability deposits on March 21–23, 1995. Contour interval 4 feet. Datum is sea level.

● 10.5 OBSERVATION WELL SCREENED IN AREA OF MODERATE TO HIGH PERMEABILITY— —Number indicates altitude of water, in feet above sea level. (Well numbers are indicated in figure 3B.)

Φ 63.5 OBSERVATION WELL SCREENED IN AREA OF LOW PERMEABILITY— —Number indicates altitude of water, in feet above sea level. Water level not used in contouring. (Well numbers are indicated in figure 3B.)

Figure 6B. Water-table altitude in March 1995, water levels in observation wells, and approximate boundaries of areas contributing ground water to selected embayments in the Sag Harbor Cove study area, eastern Suffolk County, N.Y. (Location of study area is shown in fig. 2.)

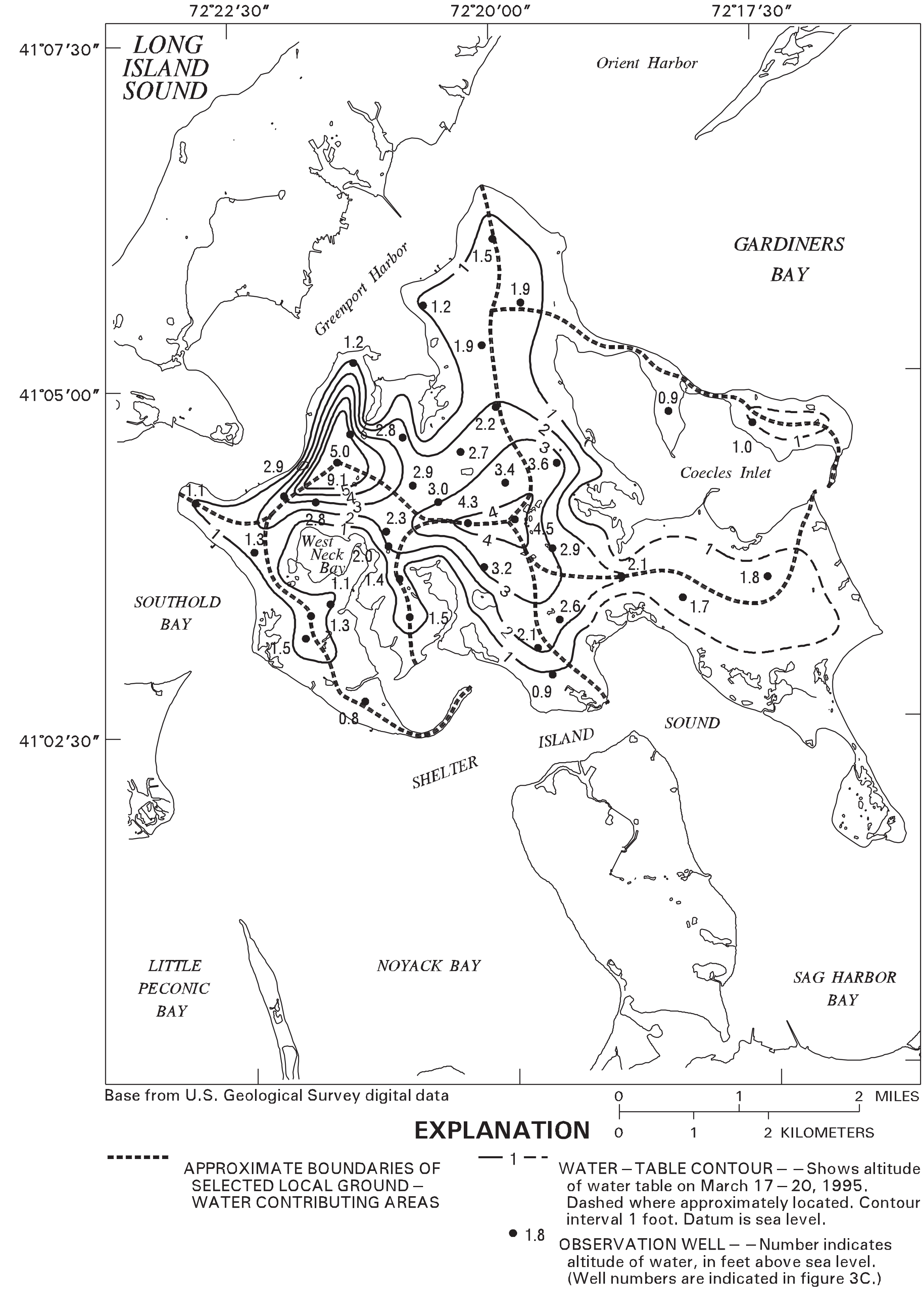

Figure 6C. Water-table altitude in March 1995, water levels in observation wells, and approximate boundaries of areas contributing ground water to selected embayments in the West Neck Creek study area, eastern Suffolk County, N.Y. (Location of study area is shown in fig. 2.)

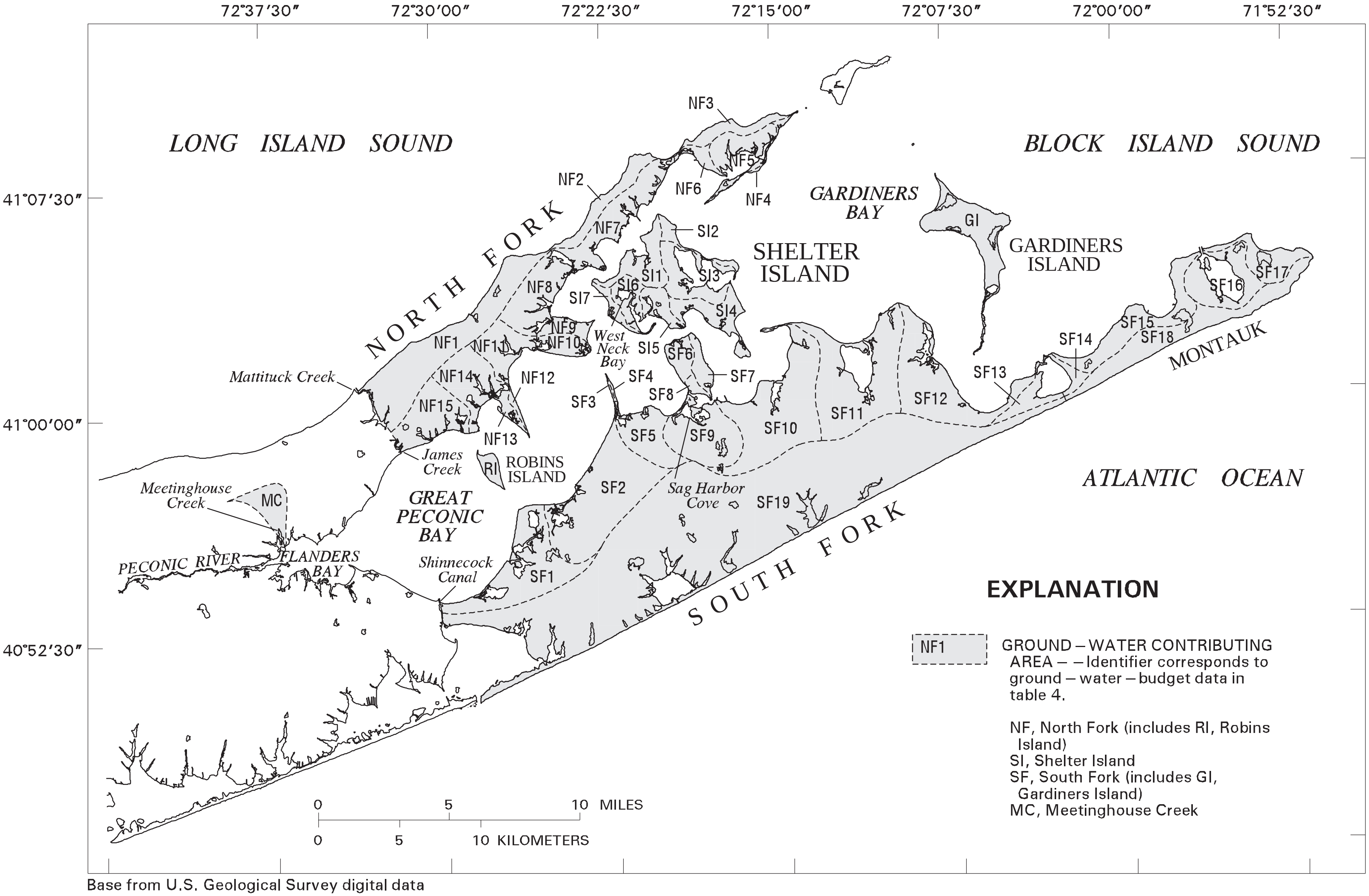

Figure 7. Locations of areas contributing ground water to selected embayments within the Peconic Estuary on the North and South Forks and Shelter Island, eastern Suffolk County, N.Y.

precipitation (table 3) and annual lake evaporation. The long-term mean rate of lake evaporation on Long Island is about 33.7 in/yr, as calculated from an average pan coefficient of 0.7, which relates the rate of annual lake evaporation to annual pan evaporation (Linsley and Franzini, 1979), and mean annual evaporation of 48.1 in. from a land pan in central Nassau County during 1949-60 (Pluhowski and Kantrowitz, 1964). Recharge to the water table through fresh surface-water bodies was applied to freshwater bodies of 10 acres or more (fig. 7) at a rate of 11.6 in/yr. Exceptions to this were the main channel of the Peconic River and brackish surface-water bodies along the shore, which were assumed to contribute no net recharge to the water table. Recharge to the water table through fresh surface-water bodies of less than 10 acres was assumed to be comparable to the rate of recharge in land areas; therefore, these small freshwater bodies were not differentiated from surrounding areas within the ground-water-budget areas.

The withdrawal of ground water for public supply, and the return flow of public-supply water in unsewered areas, were evaluated for land areas of the contributing areas shown in figure 7 that overlap the regional public water-supply systems within the ground-water-budget areas (fig. 5). Public-supply withdrawal for a given contributing area was calculated as total 1994 pumpage for all well fields within that contributing area; contributing areas with no well fields were assigned a value of zero. The rate of public-supply return flow within a given public water-supply system (fig. 5) was estimated to be 85 percent of the overall rate of public-supply withdrawal within that system, as calculated from total 1994 pumpage for an individual public water-supply district (table 1), divided by its service area; all contributing areas that overlap the unsewered land areas of a given public water-supply system were assigned the same rate of public-supply return flow, regardless of the number of well fields within individual contributing areas. Public-supply return flow was applied at a rate of 2.3 in/yr to unsewered land areas within the Greenport Water District, and at rates of 4.0, 3.7, and 4.4 in/yr, respectively, to unsewered land areas within the East Hampton, Montauk, and Southampton distribution zones of the SCWA. The rate of public-supply return flow distributed to unsewered land areas within the Hampton Bays and Riverhead Water Districts (figs. 5 and 7) was assigned a value of 3.7 and 2.9 in/yr, respectively. Differences in the rates of public-supply withdrawal and return flow between public water-supply systems probably reflect differences in intensity or type of land use and water use among service areas, but may also be attributed partly to differences among techniques used to estimate the extent of service areas.

Agricultural withdrawal of ground water was evaluated for land areas of the contributing areas shown in figure 7 that coincide with the distribution of agricultural lands within the ground-water-budget areas (fig. 4). The rate of agricultural withdrawal was approximated as the mean (weighted by extent of cultivation) of the calculated seasonal irrigation requirement for selected major crops grown on Long Island (table 2). The resulting rate of agricultural withdrawal, based on nine crops, including grain (not irrigated), that occupy 81.7 percent of the available cultivated land on Long Island in 1991, was 3.0 in/yr.

Ground-water budgets for areas on the North and South Forks and Shelter Island that contribute ground water to Long Island Sound, the Peconic Estuary, and the Atlantic Ocean are given in table 4, which also includes a ground-water budget for the area on the main body of Long Island that contributes ground water to Meetinghouse Creek. The first inflow term (recharge from precipitation) represents a regional long-term average based on the assumption of no net change in the lateral dimensions of individual contributing areas through time. This assumption is probably reasonable because variations in the pattern and rate of recharge from precipitation are generally distributed uniformly across large areas and, therefore, are not likely to significantly alter the positions of contributing-area boundaries. The assumption of no net change in the lateral dimensions of individual contributing areas through time is also supported by (1) the nearly constant sea level in the adjacent tidewaters, which limits the extent to which contributing-area boundaries could change, and (2) the area's rural character with relatively small public water-supply pumpage, which probably affects most contributing-area boundaries only minimally. The second inflow term (return flow of public-supply water), together with one of the outflow terms (public-supply withdrawal), represent annual (1994) calculations and are the most reliable values in the ground-water budgets, but these terms assume no net change in public water-supply pumpage or in the service areas of the public water-supply systems through time. In reality, incremental increases in both quantities through time can be expected, and would be accompanied by annual fluctuations in

Table 4. Ground-water budgets for contributing areas on the North and South Forks and Shelter Island, eastern Suffolk County, N.Y.

[Contributing-area locations are shown in fig. 7. Acreages reported to 3 significant figures (to the nearest 10 acres) to balance contributing areas. Ground-water-budget components reported to 3 significant figures (to the nearest 100 cubic feet per day) to balance inflow and outflow. No values in this table are accurate to more than 2 significant figures, and some values may be accurate to less]

Contributing area		Inflow (cubic feet per day)		Outflow (cubic feet per day)		
Map identifier	Acreage	Recharge from precipitation	Public-supply return flow	Agricultural withdrawal	Public-supply withdrawal	Total discharge[a]
NORTH FORK AREAS CONTRIBUTING TO LONG ISLAND SOUND						
NF1	6,580	1,480,000	1,800	-98,000	-80,500	-1,300,000
NF2	1,450	325,000	23,700	-800	-5,200	-343,000
NF3	980	220,000	0	-6,400	0	-214,000
[b]Total	9,010	2,020,000	25,500	-105,000	-85,700	-1,860,000
NORTH FORK AREAS CONTRIBUTING TO PECONIC ESTUARY						
NF4	210	46,800	0	0	0	-46,800
NF5	1,610	358,000	0	-19,800	0	-338,000
NF6	460	104,000	0	-2,400	0	-102,000
NF7	2,940	659,000	36,500	-5,300	-200	-690,000
NF8	2,700	606,000	35,200	-17,000	-44,100	-580,000
NF9	680	152,000	0	0	0	-152,000
NF10	810	183,000	0	-2,900	0	-180,000
NF11	1,780	400,000	0	-25,900	0	-374,000
NF12	150	34,500	0	0	0	-34,500
NF13	370	82,800	0	0	0	-82,800
NF14	2,490	559,000	0	-30,300	0	-529,000
NF15	2,780	622,000	0	-30,700	0	-591,000
[b,c]Total	17,000	3,810,000	71,700	-134,000	-44,300	-3,700,000
RI	460	103,000	0	0	0	-103,000
[b]Total	17,400	3,910,000	71,700	-134,000	-44,300	-3,800,000
SHELTER ISLAND AREAS CONTRIBUTING TO PECONIC ESTUARY						
SI1	1,720	387,000	0	-2,200	0	-384,000
SI2	500	113,000	0	0	0	-113,000
SI3	1,680	377,000	0	0	0	-377,000
SI4	1,610	363,000	0	0	0	-363,000
SI5	840	187,000	0	-1,500	0	-186,000
SI6	880	199,000	0	-900	0	-198,000
SI7	430	97,700	0	-100	0	-97,600
[b]Total	7,670	1,720,000	0	-4,600	0	-1,720,000

Table 4. Ground-water budgets for contributing areas on the North and South Forks and Shelter Island, eastern Suffolk County, N.Y.—continued

Contributing area		Inflow (cubic feet per day)		Outflow (cubic feet per day)		
Map identifier	Acreage	Recharge from precipitation	Public-supply return flow	Agricultural withdrawal	Public-supply withdrawal	Total discharge[a]
SOUTH FORK AREAS CONTRIBUTING TO PECONIC ESTUARY						
SF1	4,750	1,060,000	11,500	-900	-74,100	-996,000
SF2	6,960	1,560,000	17,400	-3,400	-105,000	-1,470,000
SF3	40	9,400	0	0	0	-9,400
SF4	70	15,000	0	0	0	-15,000
SF5	2,180	489,000	0	-1,000	0	-488,000
SF6	830	186,000	400	0	0	-186,000
SF7	650	146,000	800	0	0	-147,000
SF8	300	67,600	5,800	0	0	-73,400
SF9	3,300	732,000	28,200	-4,000	-106,000	-649,000
SF10	6,990	1,570,000	18,800	-200	0	-1,590,000
SF11	6,680	1,500,000	2,300	-400	0	-1,500,000
SF12	5,070	1,140,000	1,300	-200	0	-1,140,000
SF13	930	209,000	3,100	0	0	-212,000
SF14	440	100,000	600	0	0	-101,000
SF15	3,070	674,000	18,400	0	-42,400	-650,000
SF16	2,360	524,000	34,100	-200	-33,300	-524,000
SF17	1,710	356,000	0	0	0	-356,000
[b,d]Total	46,300	10,300,000	143,000	-10,200	-361,000	-10,100,000
GI	3,310	682,000	0	0	0	-682,000
[b]Total	49,600	11,000,000	143,000	-10,200	-361,000	-10,800,000
SOUTH FORK AREAS CONTRIBUTING TO ATLANTIC OCEAN						
SF18	4,100	915,000	35,000	-600	-26,000	-923,000
SF19	37,400	8,270,000	584,000	-200,000	-490,000	-8,160,000
[b]Total	41,500	9,180,000	619,000	-201,000	-516,000	-9,080,000
LONG ISLAND MAINLAND AREAS CONTRIBUTING TO MEETINGHOUSE CREEK						
MC	1,370	308,000	22,900	-17,100	0	-314,000

[a] Estimate of total discharge determined from computed sum of recharge from precipitation, public-supply withdrawal and return flow, and agricultural withdrawal. The quantity may not equal the sum of these components because of rounding to significant digits.

[b] Total may not equal the sum of values because of rounding to significant digits.

[c] Total excludes quantities determined for Robins Island (map identifier RI).

[d] Total excludes quantities determined for Gardiners Island (map identifier GI).

pumpage that, in years of unusually high or low water use, can be as large as 20 percent (Paul Ponturo, Suffolk County Department of Health Services, oral commun., 1996). The remaining outflow term (agricultural withdrawal) represents a regional approximation that relies on long-term mean agricultural and climatic data and on estimated land use in 1994, and assumes no net change in agricultural or climatic factors, nor in the distribution of farmlands through time. The complexity of this term, and the uncertainty in the validity of the governing assumptions, make this term the least reliable term in the ground-water budgets. The last term in table 4 (total discharge) represents the sum of the above-mentioned ground-water-budget components for each contributing area and, therefore, can be considered an approximation based on a combination of (1) long-term, average estimates, and (2) short-term, detailed calculations, and probably is no more accurate than the least reliable quantity evaluated for each contributing area.

The ground-water budgets in table 4 indicate that total discharge to the Peconic Estuary is about 3.8×10^6 ft^3/d from the North Fork, 11×10^6 ft^3/d from the South Fork, and 1.7×10^6 ft^3/d from Shelter Island. The total contribution of fresh ground water to the estuary from the North and South Forks and Shelter Island amounts to about 16×10^6 ft^3/d—roughly twice as much as the total contribution of fresh ground water from the main body of Long Island, which is about 7.5×10^6 ft^3/d, as indicated by the USGS ground-water-flow model of the main body of Long Island (Buxton and others, 1991). In contrast to the freshwater contribution from the main body of Long Island, which is concentrated near the head of the Peconic Estuary, the freshwater contributions from the North and South Forks and Shelter Island are distributed along most of the east-west length of the estuary.

Analysis of Fluctuations in Ground-Water Discharge

The values in table 4 indicate that recharge from precipitation is by far the largest hydrologic component in the computation of total discharge from the North and South Forks and Shelter Island. Although recharge from precipitation was evaluated as a long-term mean component, it can undergo significant seasonal and longer term fluctuations. One effect of such fluctuations on fresh ground-water systems is changes in the amount of freshwater in storage; another is fluctuations in fresh ground-water discharge, although these can be moderated and damped through time by concomitant changes in the amount of freshwater storage. The time required for precipitation to infiltrate through the unsaturated zone and reach the water table also can delay the effects of fluctuations in recharge, although this delay is assumed to be relatively short because the depth to the water-table is relatively shallow in most parts of the North and South Forks and Shelter Island.

Annual total precipitation during calendar years 1976-95 at Greenport is plotted in figures 8 and 9; average annual precipitation during this interval (46.8 in.) was about 4 percent above the regional long-term average value used to calculate recharge from precipitation in the ground-water budgets. Water levels measured periodically during 1976-95 at three observation wells screened within each of the three principal freshwater flow systems of the North Fork (fig. 8) indicate that seasonal water-table fluctuations within individual years of this period generally exceeded the annual and long-term fluctuations, as did water levels measured periodically during the same time interval at two observation wells screened within the principal freshwater flow system on Shelter Island (fig. 9). These relatively large seasonal water-table fluctuations on the North Fork and Shelter Island, which are primarily a response to seasonal variations in recharge, indicate that concomitant changes in the relatively small amounts of freshwater in storage at these locations would not substantially buffer short-term fluctuations in freshwater discharge.

Annual total precipitation during calendar years 1976-95 at Bridgehampton is plotted in figure 10; average annual precipitation during this interval (46.2 in.) was about 2 percent above the regional long-term average value used to calculate recharge from precipitation in the ground-water budgets. Water levels measured periodically during 1976-95 at observation wells S8833 and S8843 (fig. 10), screened within the freshwater flow system of the main body of the South Fork, and at observation well S48579, screened within the principal freshwater flow system of the Montauk peninsula, indicate that seasonal water-table fluctuations within individual years of this period generally are comparable to the annual and long-term fluctuations, unlike those on the North Fork and Shelter Island. These relatively moderate seasonal water-table fluctuations on the main body of the South

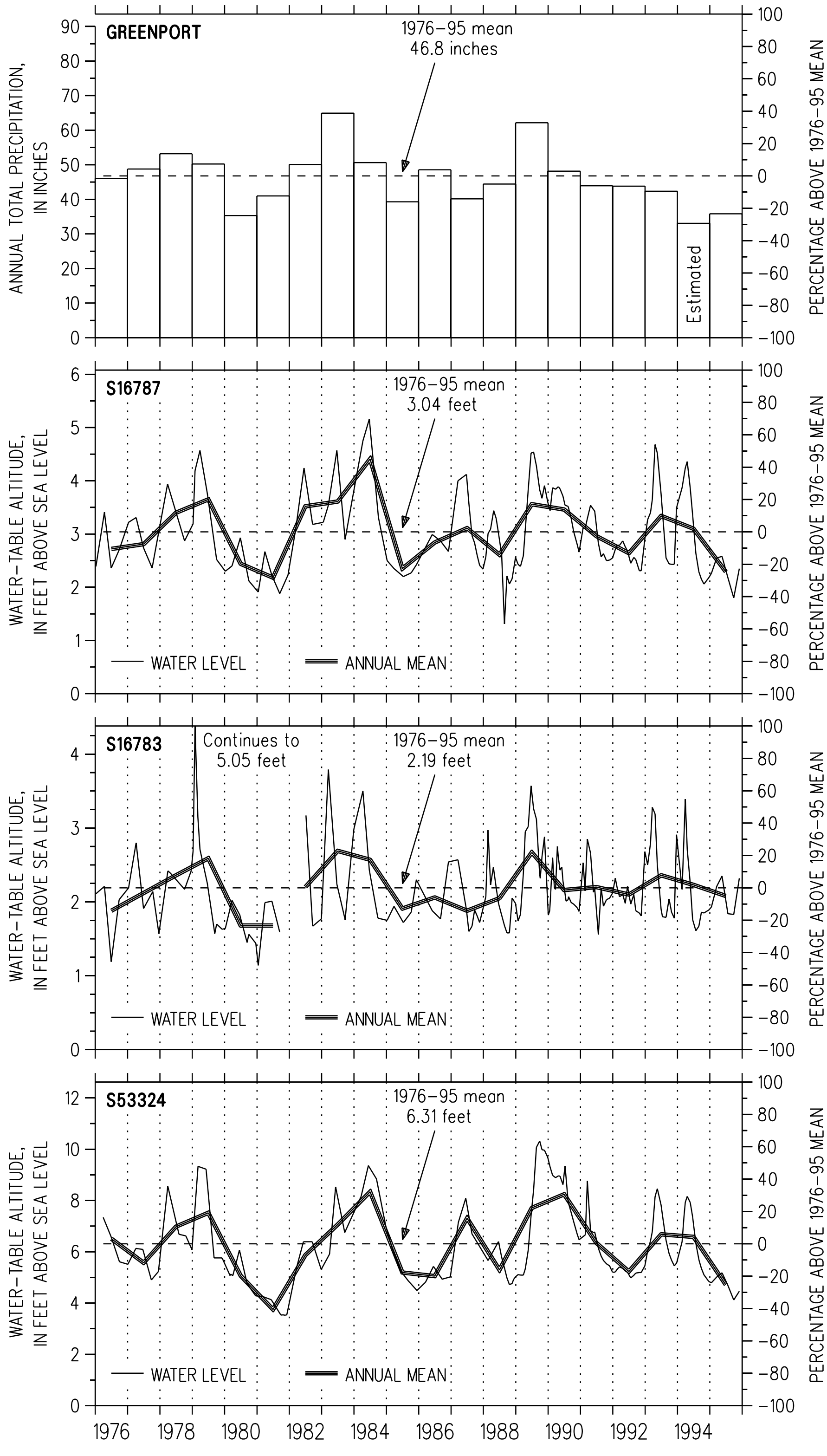

Figure 8. Annual total precipitation at Greenport and water-table altitudes in selected observation wells on the North Fork, calendar years 1976-95, eastern Suffolk County, N.Y. (Precipitation data from Kathryn Vreeland, Northeast Regional Climate Center, written commun., 1995, 1996. Precipitation-measurement station location is shown in fig. 2. Estimated values reflect unavailable data for an individual month, and were calculated from data for corresponding month from Bridgehampton station. Well locations are shown on pl. 1.)

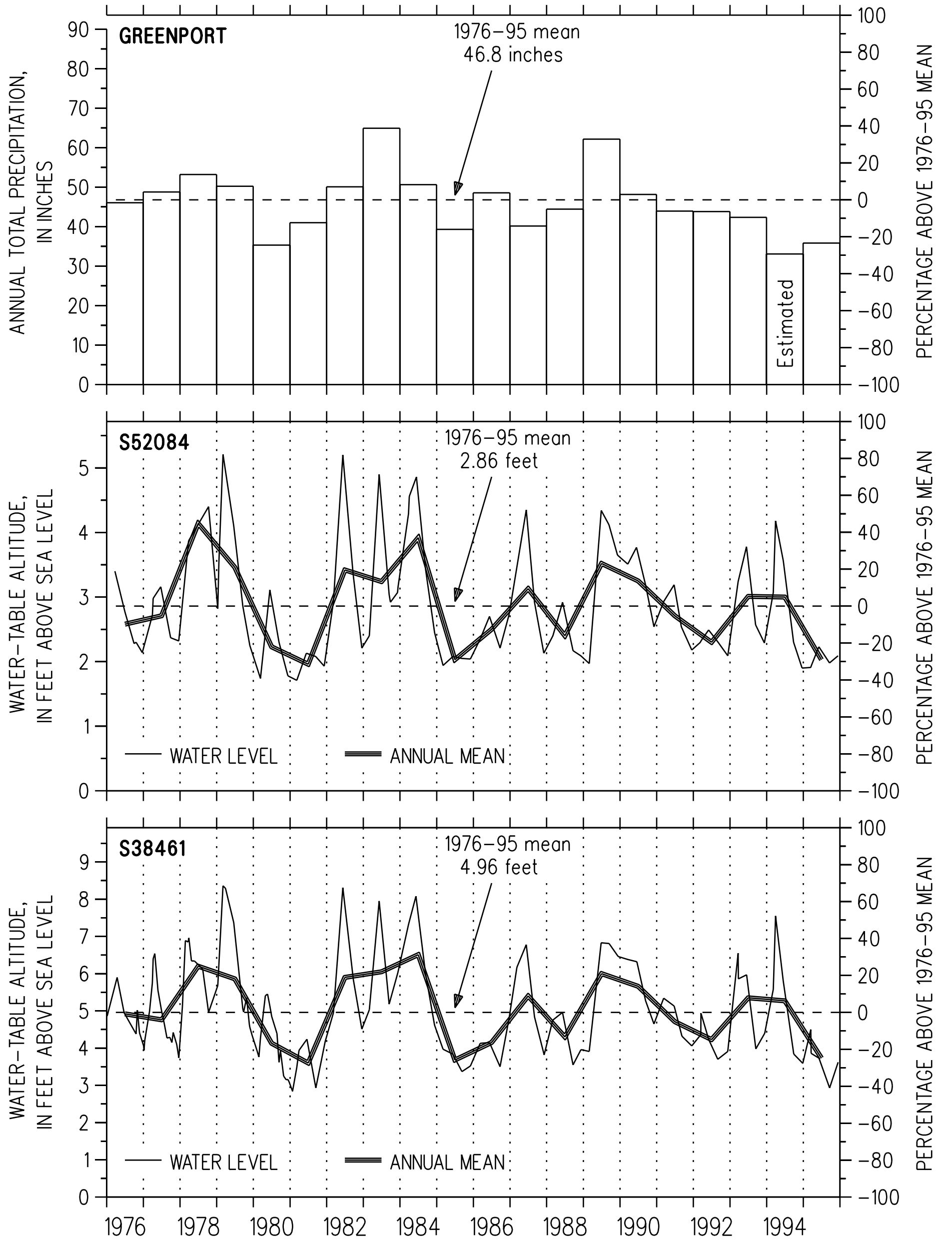

Figure 9. Annual total precipitation at Greenport and water-table altitudes in selected observation wells on Shelter Island, calendar years 1976-95, eastern Suffolk County, N.Y. (Precipitation data from Kathryn Vreeland, Northeast Regional Climate Center, written commun., 1995, 1996. Precipitation-measurement station location is shown in fig. 2. Estimated values reflect unavailable data for an individual month, and were calculated from data for corresponding month from Bridgehampton station. Well locations are shown on pl. 1.)

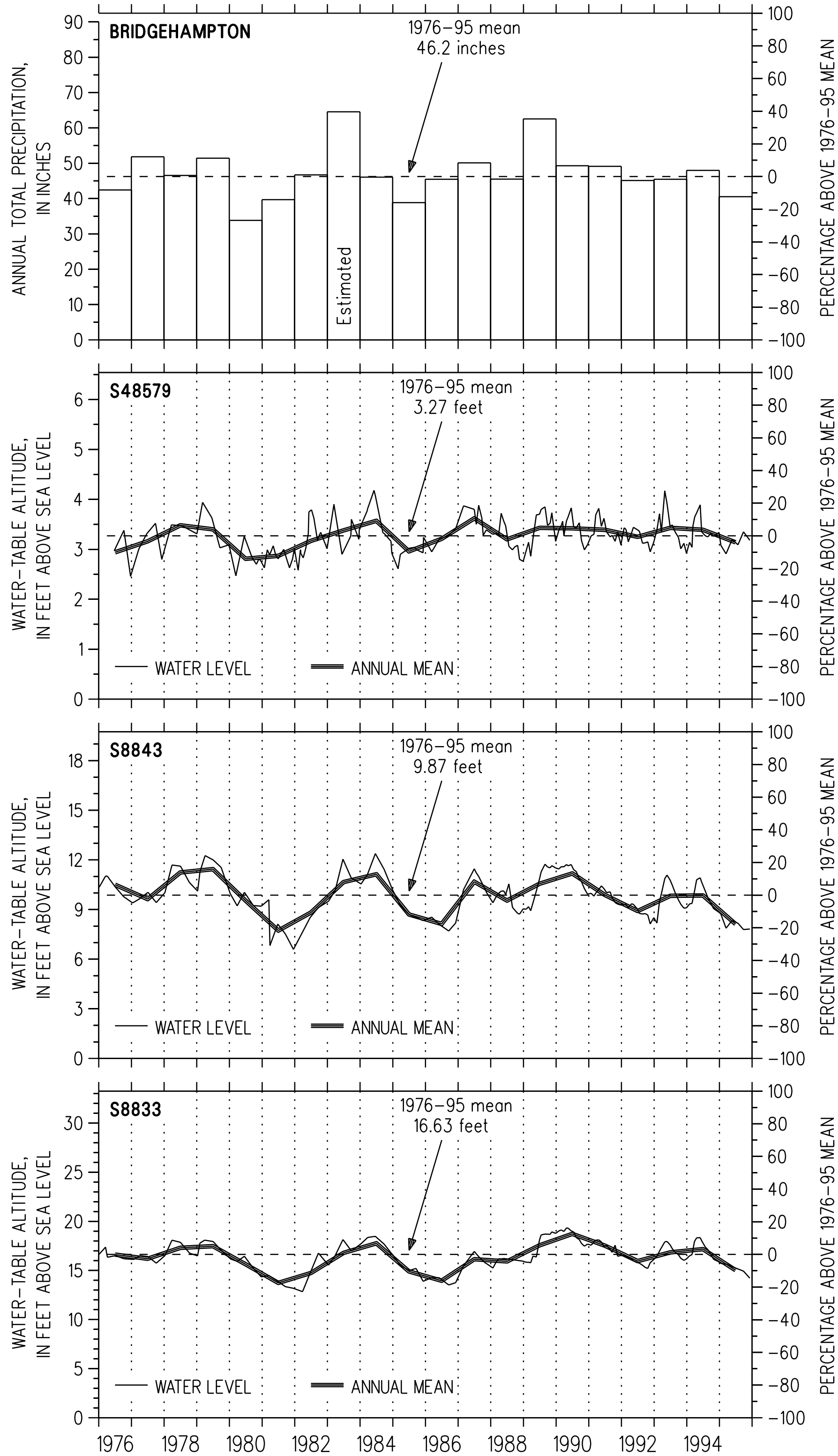

Figure 10. Annual total precipitation at Bridgehampton and water-table altitudes in selected observation wells on the South Fork, calendar years 1976-95, eastern Suffolk County, N.Y. (Precipitation data from Kathryn Vreeland, Northeast Regional Climate Center, written commun., 1995, 1996. Precipitation-measurement station location is shown in fig. 2. Estimated values reflect unavailable data for an individual month, and were calculated from data for corresponding month from Greenport station. Well locations are shown on pl. 1.)

Fork and on the Montauk peninsula indicate that concomitant changes in the relatively moderate amounts of freshwater in storage at these locations would substantially buffer short-term fluctuations in freshwater discharge.

Annual total precipitation during calendar years 1976-95 at Riverhead is plotted in figure 11; average annual precipitation during this interval (46.2 in.) was about 2 percent above the regional long-term average value used to calculate recharge from precipitation in the ground-water budgets. Water levels measured periodically during 1976-95 at observation wells on the main body of Long Island (fig. 11) indicate that seasonal water-table fluctuations within individual years generally are comparable to the annual and long-term fluctuations and that concomitant changes in the relatively large amounts of freshwater in storage at this location would substantially buffer short-term fluctuations in freshwater discharge, as on the main body of the South Fork and on the Montauk peninsula. Nevertheless, annual mean discharge of the Peconic River (measured at the USGS gage in Riverhead) during 1976-95 (fig. 11) indicates that annual and long-term fluctuations in recharge, and the resulting water-table fluctuations, cause relatively large changes in the annual mean discharge of the river. However, because the Peconic River derives about 95 percent of its total flow from ground-water seepage (Reynolds, 1982), small changes in the hydraulic gradient between the water table and land surface have a greater effect on the river discharge than on direct ground-water discharge to the Peconic Estuary from this area.

Freshwater discharge to the Peconic Estuary from the North and South Forks and Shelter Island occurs primarily as direct ground-water outflow to saltwater bodies and, to a lesser extent, as ground-water seepage to streams. Changes in the amounts of direct ground-water discharge to saltwater bodies are generally controlled by changes in the hydraulic gradient between the water table and a nearly constant sea level at the shore; therefore, relative changes in water-table altitude within a given flow system should provide reasonable estimates of the relative changes in total discharge to the Peconic Estuary from this system. The relative magnitude of changes in water-table altitude, and the resulting changes in total discharge to the estuary from the North and South Forks and Shelter Island, was estimated through an evaluation of the relative changes in annual mean water level at observation wells screened within the principal flow systems from these areas (table 5).

The results in table 5 indicate that the 1985-95 interval included 7 years (1985-88, 1991-92, 1995) of generally below-average water-table altitudes in the study area that are expected to have caused proportional decreases in the amounts of fresh ground-water discharge to the Peconic Estuary. Intense Brown Tide blooms in the Peconic Estuary coincided with six of these years (1985-88, 1991, 1995), and localized Brown Tide blooms in two Shelter Island embayments (West Neck Bay and Coecles Inlet) of the estuary coincided with the remaining year (1992) (Suffolk County Department of Health Services, 1992; Peconic Estuary Program [PEP] Program Office, 1995). The 1985-95 interval also included 4 years (1989-90, 1993-94) of nearly average or above-average water-table altitudes in the study area (table 5) that are expected to have produced comparably near-average or increased amounts of fresh ground-water discharge to the Peconic Estuary. None of these years saw any widespread Brown Tide blooms in the Peconic Estuary (Suffolk County Department of Health Services, 1992; Peconic Estuary Program [PEP] Program Office, 1995). These data appear to indicate that fluctuations in the amounts of fresh ground-water discharge to the estuary affect the occurrence of Brown Tide blooms, although the factors that trigger the blooms have not been identified. The data also support a general analysis of Peconic River discharge and water-table altitudes along the western part of the estuary (LaRoche and others, in press) indicating that Brown Tide blooms are correlated with increased estuarine salinities and inversely correlated with increased ground-water discharge, which may affect the supply of certain dissolved nutrients. Although more work would be needed to explain why Brown Tide blooms were not reported before 1985, a recent evaluation of trends in precipitation and water-table altitudes on Long Island indicates that annual precipitation was greater and more variable during the 1980's than previously and resulted in increased water-table fluctuations (Scorca, 1997). These, in turn, would have produced wider fluctuations in ground-water discharge as well. The results also indicate that continuous monitoring of precipitation, water-table altitude, and the resulting changes in fresh ground-water discharge along the Peconic Estuary could provide data to forecast future occurrences of Brown Tide blooms.

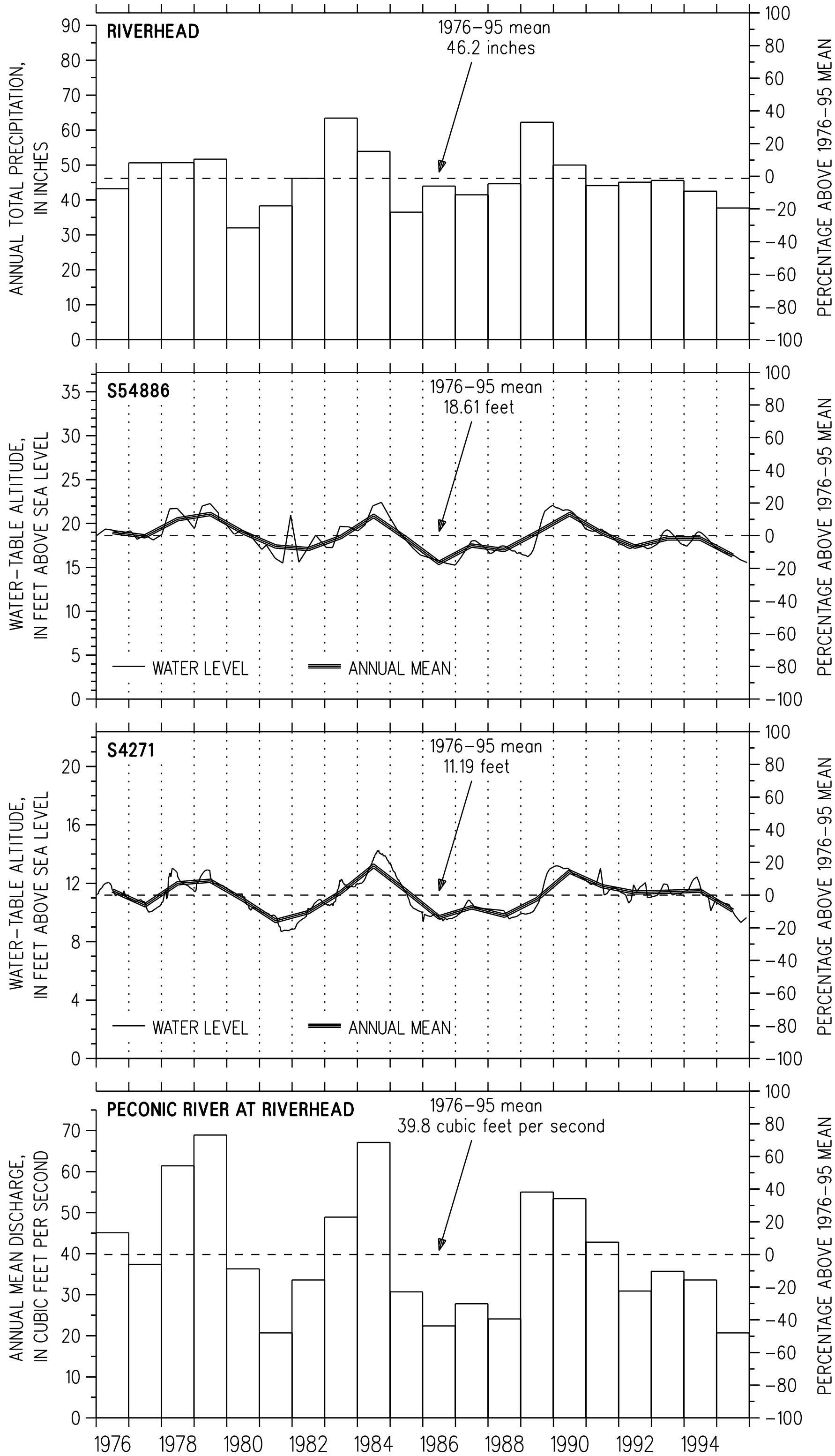

Figure 11. Annual total precipitation at Riverhead, water-table altitudes in selected observation wells on the main body of Long Island, and annual mean discharge of the Peconic River at Riverhead, calendar years 1976-95, eastern Suffolk County, N.Y. (Precipitation data from Kathryn Vreeland, Northeast Regional Climate Center, written commun., 1995, 1996. Precipitation-measurement station location is shown in fig. 2. Streamflow-gaging station location is shown in fig. 2. Well locations are shown on pl. 1.)

Table 5. Departures of annual mean water-table altitudes from long-term mean in selected observation wells on the North and South Forks and Shelter Island, and Brown Tide occurrences in the Peconic Estuary, calendar years 1976-95, eastern Suffolk County, N.Y.

[Negative values (shaded) are departures below 1976-95 mean. Dashes indicate no Brown Tide bloom reported. Annual and 1976-95 mean water-table altitudes are shown in figs. 8-11. Well locations are shown on pl. 1. Well number is assigned by New York State Department of Environmental Conservation. Prefix “S” denoting Suffolk County is omitted. Brown Tide data from Suffolk County Department of Health Services, 1992, and Peconic Estuary Program (PEP) Program Office, 1995]

	Departure of annual mean water-table altitude (percentage above or below [-] 1976-95 mean)															
	North Fork wells				Shelter Island wells			South Fork wells				Long Island mainland wells			
Year	16787	16783	53324	Average	52084	38461	Average	48579	8843	8833	Average	54886	4271	Average	Brown Tide occurrences in the Peconic Estuary[a]
1976	-11	-14	3	-7	-10	-1	-6	-10	6	0	-1	2	3	2	--
1977	-8	-3	-12	-8	-5	-4	-4	-3	-2	-3	-8	0	-6	-3	--
1978	12	8	11	10	45	25	35	6	14	4	8	10	7	8	--
1979	20	18	19	19	21	18	20	4	16	5	8	13	9	11	--
1980	-20	-23	-20	-21	-22	-17	-20	-14	-3	-6	-8	2	-3	0	--
1981	-28	-23	-41	-31	-31	-27	-29	-12	-22	-17	-17	-7	-16	-12	--
1982	16	0	-7	3	20	19	20	-3	-11	-11	-8	-8	-10	-9	--
1983	19	23	12	18	13	22	18	3	8	1	4	-1	2	0	--
1984	45	17	32	31	37	31	34	9	13	7	10	12	18	15	--
1985	-23	-13	-18	-18	-29	-26	-28	-9	-12	-10	-10	-2	3	0	intense blooms
1986	-7	-6	-20	-11	-13	-16	-14	-2	-18	-16	-12	-17	-14	-16	intense blooms
1987	2	-14	16	1	9	9	9	11	8	-3	5	-6	-8	-7	intense blooms
1988	-14	-6	-16	-12	-16	-13	-14	-2	-3	-4	-3	-9	-13	-11	intense blooms
1989	17	22	22	20	23	21	22	5	7	6	6	2	-3	0	--
1990	14	-1	31	15	14	14	14	5	13	13	10	13	14	14	localized, elevated cell counts[b]
1991	-3	0	0	-1	-5	-5	-5	4	0	5	3	2	5	4	intense blooms
1992	-13	-4	-17	-11	-20	-15	-18	-1	-10	-4	-5	-7	2	-2	localized, high concentrations[c]
1993	10	8	6	8	5	8	6	5	0	1	2	-2	2	0	--
1994	2	2	4	3	5	6	6	4	0	3	2	-2	3	0	--
1995	-25	-5	-25	-18	-29	-25	-27	-4	-18	-10	-11	-12	-9	-10	intense blooms

[a] Brown Tide blooms were not reported in the Peconic Estuary before 1985.
[b] Elevated Brown Tide cell counts reported in West Neck Bay.
[c] High concentrations of Brown Tide cells reported in West Neck Bay and Coecles Harbor.

SUMMARY AND CONCLUSIONS

The Peconic Estuary has been repeatedly plagued since 1985 by the "Brown Tide," an unusual algal bloom that has caused the severe decline of local marine resources. Although the onset, duration, and cessation of the Brown Tide remain unpredictable, ground-water discharge has previously been shown to affect surface-water quality in the western part of the Peconic Estuary. Results from a USGS ground-water-flow model of Long Island indicate that a total of about 7.5 x 10^6 ft^3/d of freshwater is discharged to the western part of the estuary from the main body of Long Island and that nearly two-thirds of this (about 4.7 x 10^6 ft^3/d) is contributed by the Peconic River; the rest is contributed as direct ground-water discharge to Flanders Bay and the western part of Great Peconic Bay (about 1.9 x 10^6 and 0.92 x 10^6 ft^3/d, respectively). The model does not simulate the ground-water flow systems on the North and South Forks and Shelter Island, which are hydraulically isolated from the ground-water-flow system of the main body of Long Island but contribute freshwater to the central and eastern parts of the estuary. The need for information on ground-water discharge to the entire Peconic Estuary prompted the USGS to evaluate ground-water discharge from the North and South Forks and Shelter Island.

Areas contributing ground water to the Peconic Estuary were delineated, and ground-water budgets for these areas were developed, to provide data on the distribution and magnitude of ground-water discharge to the central and eastern parts of the estuary. This effort focused on the North and South Forks and Shelter Island, with emphasis on the uplands of three small embayments (Meetinghouse Creek, near the west end of the North Fork; Sag Harbor Cove, on the South Fork; and West Neck Bay, on Shelter Island). The fresh ground-water reservoirs on the North and South Forks and Shelter Island consist of a series of hydraulically distinct freshwater lenses, bounded by saltwater, within a vertical sequence of unconsolidated deposits. All drinking water and irrigation water on the North Fork and Shelter Island is withdrawn from the upper glacial aquifer; the deep aquifers in both areas contain mostly saline ground water and are not used for water supply. On the South Fork, most water is withdrawn from the upper glacial aquifer, but some is withdrawn from the underlying Magothy aquifer.

Contributing-area boundaries that were delineated coincide with the hydraulic boundaries of the fresh ground-water-flow systems of the North and South Forks and Shelter Island. These boundaries are of two types—external (saltwater bodies) and internal (ground-water divides). External boundaries are represented by saline ground waters and surface waters that separate or isolate individual freshwater flow systems, and internal boundaries are represented by local and regional ground-water divides that separate flow subsystems, or groups of flow subsystems, from one another within the larger flow systems. Hydrologic components that were evaluated for the contributing areas include recharge from precipitation, public-supply withdrawal and return flow, and agricultural withdrawal. Values for each of these components were calculated or estimated for the individual freshwater flow subsystems that form each ground-water-budget area and were then summed to obtain the total discharge of fresh ground water from these systems to tidewater.

Ground-water discharge to the Peconic Estuary is about 3.8 x 10^6 ft^3/d from the North Fork, 11 x 10^6 ft^3/d from the South Fork, and 1.7 x 10^6 ft^3/d from Shelter Island. The total contribution of fresh ground water to the estuary from these areas is about 16 x 10^6 ft^3/d—roughly twice as much as the total contribution from the main body of Long Island. In contrast to the freshwater contribution from the main body of Long Island, which is concentrated near the head of the Peconic Estuary, the freshwater contributions from the North and South Forks and Shelter Island are distributed along most of the east-west length of the estuary.

The relative magnitude of changes in water-table altitude, and the resulting changes in total discharge to the Peconic Estuary from the North and South Forks and Shelter Island, was estimated through an evaluation of the relative changes in annual mean water level at observation wells screened within the principal flow systems from these areas. Results indicate that the 1985-95 interval included 7 years (1985-88, 1991-92, 1995) of generally below-average water-table altitudes that are expected to have caused proportional decreases in the amounts of fresh ground-water discharge to the Peconic Estuary; intense Brown Tide blooms in the estuary coincided with six of these years (1985-88, 1991, 1995), and localized blooms in two Shelter Island embayments (West Neck Bay and Coecles Inlet) of the estuary coincided with the remaining year (1992). The 1985-95 interval also included 4 years (1989-90, 1993-94) of nearly-average or above-average water-table altitudes that are expected to have produced comparably near-average or increased amounts of fresh ground-water discharge to the Peconic Estuary; none of these years saw any widespread Brown Tide blooms in the estuary. These data appear to indicate that fluctuations in the amounts of fresh ground-water discharge to the Peconic Estuary affect the occurrence of Brown Tide blooms, although the factors that trigger the blooms have not been identified.

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